

The background image is a photograph of a swampy landscape. Several large, dark, gnarled cypress trees stand in shallow water. Their reflections are visible in the calm water. In the background, there is a line of trees and a clear blue sky. The overall scene is serene and natural.

U.S. Fish & Wildlife Service

Mingo, Pilot Knob, and Ozark Cavefish National Wildlife Refuges

Water Resource Inventory and Assessment (WRIA) Summary Report

[04/10/2017]

U.S. Department of the Interior
Fish and Wildlife Service
Region 3 (Midwest Region)
Division of Natural Resources and Conservation Planning;
Bloomington, MN

Cover Image: Monopoly Marsh December 2016- James Stack



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The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservation, management and, where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans.

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Author's Note:

There are embedded links throughout this document within the table of contents and indicated by underlined text. A database of the presented data, additional data, documents and the referenced studies will be available as part of a digital document library housed on the Environmental Conservation Online System (ECOS). Geospatial data layers were obtained from the U.S. Fish and Wildlife Service, USGS seamless server, the Environmental Protection Agency, and the Missouri Spatial Data Information Services website.

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Table of Contents

1. Executive Summary	1
1.1 Findings	3
Mingo National Wildlife Refuge	3
Pilot Knob National Wildlife Refuge	4
Ozark Cavefish National Wildlife Refuge	4
1.2 Recommendations	6
Mingo National Wildlife Refuge	6
Pilot Knob National Wildlife Refuge	6
Ozark Cavefish National Wildlife Refuge	7
2. Introduction	9
Mingo National Wildlife Refuge	10
Pilot Knob National Wildlife Refuge	12
Ozark Cavefish National Wildlife Refuge	14
3. Natural Setting	17
3.1 Hydrologic Unit Codes (HUCs).....	17
Mingo National Wildlife Refuge	17
Pilot Knob National Wildlife Refuge	20
Ozark Cavefish National Wildlife Refuge	22
3.2 Ozark Cavefish NWR Groundwater RHI.....	25
3.3 Topography	30
3.4 Historic and Long-Term Climate Trends	34
Historical climate conditions.....	34
Mingo National Wildlife Refuge	34
Pilot Knob National Wildlife Refuge	35
Ozark Cavefish National Wildlife Refuge	35
Long-term projections	36
PRISM and USHCN Datasets.....	37
Mingo National Wildlife Refuge	37
Pilot Knob National Wildlife Refuge	41
Ozark Cavefish National Wildlife Refuge	44
Hydroclimatic Data Network.....	51
4. Water Resource Features	54
4.1 Management Units	54
4.2 National Wetlands Inventory	58
4.3 National Hydrography Dataset	61
5. Water Resource Monitoring	70
5.1 Water Monitoring Stations and Sampling Sites	70
5.2 Surface Water Quantity.....	74
Mingo NWR.....	74
Monopoly Marsh near Puxico, MO.....	74
Brush Creek near Puxico, MO	75
McGee Creek near McGee, MO	75
Lick Creek near McGee, MO	76
Stanley Creek near Puxico, MO.....	77
Flat Mingo Creek near Puxico.....	78
Turkey Creek.....	78
Other Mingo Water Quantity Monitoring Stations	78
St. Francis River at Wappapello, MO.....	79
Castor River at Greenbrier, MO	79
Turnback Creek near Greenfield, MO.....	80
Hickory Creek Near Neosho, MO	83

5.3 Groundwater Levels.....	84
Duck Creek	85
Mt. Vernon Ozark Aquifer.....	85
Neosho Ozark Aquifer.....	85
5.4 Water Quality Criteria.....	88
5.5 Surface Water Quality	90
Mingo National Wildlife Refuge	90
Pilot Knob National Wildlife Refuge	91
Ozark Cavefish National Wildlife Refuge	92
303(d) assessments.....	95
Mingo NWR.....	95
Pilot Knob NWR	97
Ozark Cavefish NWR	97
Contaminant Assessment Process (CAP)	100
Mingo NWR.....	100
Pilot Knob NWR	100
Ozark Cavefish NWR	101
6. Water Law	102
7. Geospatial Data Sources	104
8. Literature Cited	105
9. Appendix A: Relevant Water Monitoring Locations	108
10. Appendix B: USHCN Figures.....	110
Mingo National Wildlife Refuge	110
Pilot Knob National Wildlife Refuge	114
Ozark Cavefish National Wildlife Refuge	118
Turnback Cave Unit	118
Hearrell Spring Unit.....	120
11. Appendix C: Refuge Water Management Infrastructure.....	123

Figures

Figure 2.1: Locations of National Wildlife Refuges in southern Missouri (USFWS 2007)	9
Figure 2.2: Reference map of Mingo NWR.....	11
Figure 2.3: Reference map of Pilot Knob NWR	13
Figure 2.4: Reference map of Ozark Cavefish NWR- Turnback Cave Unit.....	15
Figure 2.5: Reference map of Ozark Cavefish National Wildlife Refuge- Hearrell Spring Unit	16
Figure 3.1: Position of Mingo NWR in relation to local major watersheds	18
Figure 3.2: Map of Mingo NWR HUC regions.....	19
Figure 3.3: Map of Pilot Knob NWR HUC regions	21
Figure 3.5: Figure of Ozark Cavefish National Wildlife Refuge- Hearrell Spring unit HUC regions	24
Figure 3.6: Map of Groundwater Provinces in Missouri (USFWS 2014)	26
Figure 3.7: Map of groundwater elevations in the area surrounding OCNWR	27
Figure 3.8: Map of Turnback Cave recharge area (MDC 2005).	28
Figure 3.9: Map of Wallbridge Spr recharge area, including Hearrell Spr recharge area (MDC 2011)	29
Figure 3.15: Average total monthly precipitation (1981-2010), Station No. 236791, Poplar Bluff, MO	39
Figure 3.16: Average monthly temperatures (1981-2010), Station No. 236791, Poplar Bluff, MO	39
Figure 3.17: Length of growing season (last freeze in Spring to first freeze in Fall) for Poplar Bluff, MO 1893-2015. Red line is a fitted linear regression, black line is a Loess regression (span = 0.5)	40
Figure 3.18: Avg number of extreme prcp events (> 2 in in a day) for Poplar Bluff, MO (1893-2015).	41
Figure 3.25: Average annual discharge data for Current River at Van Buren, MO (1963-2016) (USGS-07067000). Black line is a fitted linear regression, red line is a Loess regression	52
Figure 3.26: Average annual discharge data for Turnback Creek near Greenfield, MO (1965-2015) (.....	52
Figure 4.1: Management units at Mingo NWR (USFWS 2007)	55
Figure 4.2: Water control structures and drainage ditches at MNWR (northeast)	56
Figure 4.3: Water control structures and drainage ditches at MNWR (southwest)	57
Figure 4.4: Wetland types found at MNWR	58
Figure 4.8: Map of NHD flowlines at MNWR.....	62
Figure 4.9: Map of NHD Flowlines near PKNWR	64
Figure 4.10: NHD Flowlines found at OCNWR-Turnback Cave Unit.....	66
Figure 4.11: NHD flowlines found near OCNWR-Hearrell Spring Unit	68
Figure 5.1: Locations of applicable USGS and FWS water monitoring stations at Mingo NWR	71
Figure 5.2: Locations of applicable USGS and FWS water monitoring stations for Ozark Cavefish NWR- Turnback Cave Unit	72
Figure 5.4: Daily averaged stage (2009-2016) for (FWS-365718090132500), Monopoly Marsh near Puxico, MO.....	74
Figure 5.5: The Brush Creek watershed (north of Ditch 1)	75
Figure 5.7: The Lick Creek watershed (northwest of Ditch 10).....	77
Figure 5.8: The Stanley Creek and Kentucky Slough watersheds (West of Ditch 10 and Mingo Creek)... ..	78
Figure 5.9: Annual peak and average discharge (1941-2015) (USGS-07039500), St. Francis River at Wappapello, MO	79
Figure 5.10: Daily averaged stage (2001-2016) for USGS-07021020, Castor River nr Greenbriar, MO ...	80
Figure 5.11: Daily averaged flow (1965-2016) for USGS-06918460, Turnback Creek nr Greenfield, MO ..	81
Figure 5.12: Avg monthly flow (1965-2015) for USGS-06918460, Turnback Creek, nr Greenfield, MO....	81
Figure 5.13: Average annual and peak flow (1965-2015) for USGS-06918460, Turnback Creek, near Greenfield, MO	82
Figure 5.14: Flow exceedence curve for USGS-06918460, Turnback Creek, nr Greenfield, MO.....	82
Figure 5.15: Daily averaged flow (2012-2016) for USGS-07186900 Hickory Creek near Neosho, MO.....	83
Figure 5.16: Monthly average flows (2012-2016) for USGS-07186900, Hickory Creek near Neosho, MO.....	84
Figure 5.17: Flow exceedence curve (2012-2016) for USGS-07186900 Hickory Creek nr Neosho, MO ..	84
Figure 5.18: Daily average groundwater depth with 5-year moving average (1957-2016) for Duck Creek well (USGS-370248090042601)	86
Figure 5.19: Average Monthly Depth to Groundwater (1957-2015) for (USGS-370248090042601), Duck Creek well.....	86

Figure 5.20: Annual mean, minimum, and maximum depth to groundwater (1957-2015) for (USGS-370248090042601), Duck Creek well.....	87
Figure 5.21: Daily average depth to groundwater (2007-2016) for.....	88
Figure 5.22: Average monthly depth to groundwater (2007-2016) for USGS-370539093494001, Mt. Vernon, Ozark Aquifer well	88
Figure 5.23: Daily average depth to groundwater (2005-2016) for (USGS-364818094185302), Neosho Ozark Aquifer well	88
Turnback Cave Unit has an impaired section of river passing through the Refuge boundaries. There are 19.9 miles of Turnback Creek that are list by the State of Missouri as impaired due to <i>E. coli</i> from rural nonpoint sources and affects Whole Body Contact designated use. Aquatic life and Secondary Contact Recreation are listed as unaffected. Additionally, there are three miles of a tributary to Goose Creek that are impaired due to <i>Escherichia coli</i> . Goose Creek lies a short distance upstream of Turnback Cave. For average <i>E. coli</i> concentrations in Turnback Creek see Table 5.3.	97
The Hearrell Spring Unit does not have any impaired waters directly within its boundaries. However, there are 4.9 miles of Hickory creek nearby that are impaired due to <i>Escherichia coli</i> from rural nonpoint sources. Hickory Creek does not directly affect the Refuge (see Section 3.1 for more details).....	97
Figure 5.30: Map of impaired waters near OCNWR- Hearrell Spring Unit	99
Figure 10.1: Water Year Total Precipitation (1895-2015), Station No. 236791, Poplar Bluff, MO	110
Figure 10.2: Average cool season precipitation (1895-2015), Station No. 236791, Poplar Bluff, MO	110
Figure 10.3: Water year average trends in maximum, minimum, and mean temperatures (1895-2015), Station No. 236791, Poplar Bluff, MO.....	111
Figure 10.4. Average seasonal temperatures (1895-2015) , Station No. 236791, Poplar Bluff, MO	112
Figure 10.6: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1895-2015), Station No. 236791, Poplar Bluff, MO.....	113
Figure 10.11: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1919-2015), Station No. 232809, Farmington, MO	116
Figure 10.12: Average monthly maximum temperature versus Pacific/North American pattern phase (1919-2015), Station No. 232809, Farmington, MO	117
Figure 10.16: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1961-2012), Station No. 235862, Mt. Vernon, MO.....	119
Figure 10.20: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1896-2015), Station No. 235976, Neosho, MO	122
Figure 10.21: Average monthly maximum temperature versus Southern Oscillation Index phase (1896-2015), Station No. 235976, Neosho, MO	123
Figure 10.22: Average monthly maximum temperature versus Pacific/North American pattern pase(1896-2015), Station No. 235976, Neosho, MO	123
11. Appendix C: Refuge Water Management Infrastructure	123

Tables

Table 3.1: Statistically significant climate trends for 1895-2015, Station No. 236791, Poplar Bluff, MO ...	38
Table 3.2: Cumulative frequency of daily rain for Poplar Bluff, MO	40
Table 3.3: Cumulative frequency of daily maximum temperature (F) for Poplar Bluff, MO	41
Table 3.4: Statistically significant climate trends for 1919-2015, Station No. 232809, Farmington, MO	42
Table 3.5: Cumulative frequency of daily rain for Farmington, MO.	44
Table 3.6: Statistically significant climate trends for 1961-2012, Station No. 235862, Farmington, MO	45
Table 3.7: Statistically significant climate trends for 1919-2015, Station No. 235976, Neosho, MO	48
Table 3.8: Cumulative frequency of daily rain for Poplar Bluff, MO.	50
Figure 3.9: Cumulative frequency of daily maximum temperature (F) for Poplar Bluff, MO	51
Table 4.1: Wetland types and acreage at MWNR.....	59
Figure 4.5: Wetland types found near PKNWR	59
Figure 4.6: Wetland types found near OCNWR- Turnback Cave Unit	60
Figure 4.7: Wetland types found at OCNWR- Hearrell Spring Unit	61
Table 4.2: NHD flowlines found at Mingo NWR	63
Table 4.3: NHD flowline types found at Mingo NWR	63
Table 4.4: NHD flowlines found at PKNWR	65
Table 4.5: NHD flowline types found at PKNWR	65
Table 4.6: NHD flowlines found at OCNWR- Turnback Cave Unit	67
Table 4.7: NHD flowline types found at OCNWR- Turnback Cave Unit	67
Table 4.8: NHD flowline types found near OCNWR-Hearrell Spring	69
Table 4.9: NHD flowline types found near OCNWR-Hearrell Spring	69
Table 5.1: Flood frequency analysis results using PeakFQ (1966-2016) for USGS-06918460, Turnback Creek near Greenfield, MO	83
Table 5.2: Nutrient criteria for rivers/streams and lakes/reservoirs established for ecoregion X: Texas-Louisiana Coastal and Mississippi Alluvial Plains (EPA 2001) (Lakes and Reservoirs still under development)	89
Table 5.3: Nutrient criteria for rivers/streams and lakes/reservoirs established for ecoregion XI: Central and Eastern Forested Uplands (EPA 2000).....	89
Table 5.4: Statistics of selected water quality parameters for Turnback Creek at Paris Springs Conservation Area	94
Table 9.1: Water monitoring stations particularly relevant to Mingo, Pilot Knob, and Ozark Cavefish management	109
Table 11.1 Management units and acreage at MNWR.....	124
Table 11.2. Water Control Structures found at MNWR.....	126
Table 11.3: Water Control Structure elevations at MNWR	127

1. Executive Summary

The Water Resource Inventory and Assessment (WRIA) is a reconnaissance-level effort, which provides:

- Descriptions of local hydrology, topography, and natural setting information
- Historic, current, and projected climate information, including hydroclimate trends
- An inventory of surface water and groundwater resource features
- An inventory of relevant infrastructure and water control structures
- Summaries of historical and current water resource monitoring, including descriptions of datasets for applicable monitoring sites
- Brief water quality assessments for relevant water resources
- A summary of state water laws
- A compilation of main findings and recommendations for the future

The WRIA provides inventories and assessments of water rights, water quantity, water quality, water management, climate, and other water resource issues for each Refuge. The long-term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date, accurate data on Refuge System water quantity and quality in order to acquire, manage, and protect adequate supplies of water. Achieving a greater understanding of existing information related to Refuge water resources will help identify potential threats to those resources and provide a basis for recommendations to field and Regional Office staff. Through an examination of previous patterns of temperature and precipitation, and an evaluation of forward-looking climate models, the U.S. Fish and Wildlife Service (USFWS) aims to address the effects of global climate change and the potential implications on habitat and wildlife management goals for a specific Refuge.

WRIAs have been recognized as an important part of the NWRS Inventory and Monitoring (I&M) initiative and are identified as a need by the Strategic Plan for Inventories and Monitoring on National Wildlife Refuges: Adapting to Environmental Change (USFWS 2010a, b). I&M is one element of the U.S. Fish and Wildlife Service's climate change strategic plan to address the potential changes and challenges associated with conserving fish, wildlife and their habitats (USFWS 2011). Water Resource Inventory and Assessments have been developed by a national team comprised of U.S. Fish and Wildlife Service water resource professionals, environmental contaminants biologists, and other Service employees.

The WRIA summary narrative supplements existing and scheduled planning documents, by describing current hydrologic related information and providing an assessment of water resource needs and issues of concern. The WRIA will be a useful tool for Refuge management and complements other Refuge assessments, such as a HydroGeomorphic analysis (HGM), Comprehensive Conservation Plan (CCP), Habitat Management Plan (HMP), Contaminants Assessment Process and Inventory & Monitoring Plan (IMP). Mingo, Pilot Knob, and Ozark Cavefish had a combined CCP completed in 2007. Additionally Mingo has a CAP (Hundley 2013), an HMP (USFWS 2011), and an HGM (Heitmeyer et al. 2006). For Ozark Cavefish National Wildlife Refuge, the HMP (USFWS 2016) is also complete, and the CAP is expected to be completed by early 2017. Many of the findings and recommendations from these

assessments are applicable to water resources and are reiterated in the WRIA summary narrative.

This Water Resource Inventory and Assessment (WRIA) Summary Report for Mingo, Pilot Knob and Ozark Cavefish NWR's describes current hydrologic information, provides an assessment of water resource needs and issues of concern, and makes recommendations regarding Refuge water resources. As part of the WRIA effort for this Refuge, water resources staff in the Division of Natural Resources and Conservation Planning (NWRS) received review comments and edits from Brad Pendley, Ben Mense, and Corey Kudma

This Summary Report synthesizes a compilation of water resource data contained in the national interactive online WRIA database (<https://ecos.fws.gov/wria/>). The information contained within this report and supporting documents will be entered into the national database for storage, online access, and consistency with future WRIAs. The database will facilitate the evaluation of water resources between regions and nationally. This report and the database are intended to be a reference for ongoing water resource management and strategy development. This is not meant to be an exhaustive nor a historical summary of water management activities at refuges listed above.

1.1 Findings

Mingo National Wildlife Refuge

Mingo National Wildlife Refuge is a 21,592-acre Refuge located in both Stoddard and Wayne counties, Missouri. The Refuge resides mainly in a shallow basin that is an abandoned channel of the Mississippi bordered to the West by the Ozark Plateau and to the East by Crowley's Ridge (USFWS 2007). Mingo NWR's unique hydrologic location makes for a very complex system of inputs and outputs. The Refuge's area accounts for 40% of the Mingo Swamp HUC-12 drainage and 27% of the Mingo Swamp HUC-10 drainage (Figure 3.2). Much of the area that drains into Mingo NWR originates in the Ozark Highlands. In addition to its unique role within its own basin, Mingo NWR is interesting in that it lies in very close proximity to several HUC-8 boundaries. Although contained within the Lower St. Francis River catchment, the Refuge is bordered to the west by the Upper St. Francis River and Lake Wappapello, to the east by the Little Rivers Ditches (Castor River HUC-10), and to the north by the Whitewater River catchment (Figure 3.1).

The Castor River can flood onto the Mingo NWR and adjoining Duck Creek Conservation Area (CA) as often as four to five times per year via overland sheet flow and diversion ditches (Refuge Staff, personal communication 2016). The Lower St. Francis River can influence Mingo NWR during times of high flooding by causing a backwater effect on the Mingo Ditch. However, this is a very rare occurrence (Refuge staff, personal communication 2016). Some of Mingo's source water supply is shared with the Missouri Department of Conservation's (MDC) Duck Creek CA. Duck Creek CA shares eight miles of boundaries with Mingo NWR and Mingo's Pool #8 is directly connected with Duck Creek's Pool #1 by way of a Obermeyer water control structure. Refuge staff must coordinate closely with MDC employees in any water management decisions, especially during the fall waterfowl hunting season (Refuge staff, personal communication, 2016). Mingo staff and the MDC have maintained a great relationship historically and water management between the two agencies has been very cooperative.

The Refuge manages habitat for moist soil impoundments as well as green tree reservoirs, semi-permanent marshes, and permanent ponds. As such, water data is of critical importance to the biologists and maintenance staff to ensure proper water timing and levels for these various habitat types. In recent years, understanding of water levels on the Refuge has greatly improved. Water control structures and staff gages have all been surveyed to mean sea elevation (MSL), LiDAR elevation data has been gathered for the basin, and bathymetry surveys were conducted on Refuge units, and several studies have modeled hydrologic flow in the Refuge. In addition, gaging operations were set on the Refuge's tributaries and outputs in order to better understand the water balance of the Mingo Basin. Originally there were seven continuous streamflow gages covering the majority of Mingo's tributaries, Monopoly Marsh, and the Mingo Drain outlet. However, due to the time intensive nature of maintaining all of these gages, many were discontinued, and there are now only three (USFWS, unpublished internal data). One is on Ditch #2, the Refuge's main input/tributary, one is in Monopoly Marsh, the Refuge's largest contiguous wetland, and one is on Mingo Ditch (Ditch #15), the Refuge's outlet to the St. Francis River downstream.

Water supply on the Refuge is more than adequate most years and in fact, Mingo often suffers from too much water and an inadequate capacity to drain the water to meet habitat management objectives. However, some years water supply is insufficient in the fall to flood all units to their desired levels (Refuge staff, personal communication, 2016). Mingo is covered by a series of ditches, but in the past, the main hindrance to draining floodwaters is attributed to the water control structure located at the downstream end of the Refuge on the Mingo Ditch (Refuge staff, personal communication, 2016). The water control structure at this location essentially drains the entire Mingo Swamp Basin, an estimated 90 square miles (Woods 2004),

and its capacity is currently insufficient. Now, a newly constructed water control structure at this location is expected to reduce issues with prolonged flooding on the refuge, due to its greatly increased discharge capacity (Refuge staff, personal communication 2016)

Siltation is also a major issue for Mingo NWR's ditches and water control structures. Over time fine sediment has filled many ditches and woody debris, vegetation, and beaver dams have caused an impediment to flow through ditches and water control structures. This ongoing maintenance issue for Refuge Staff has been of primary concern since the 1990s. The staff has a goal of clearing one mile of ditch per year (USFWS 2007). With 79 miles of ditches and streams within the Refuge and its immediate vicinity, this is likely to be an ongoing task unless the causes can be addressed.

There is a man-made plug on Ditch 10 (Figure 4.3, Item # 17) that impounds water into the Stanley Creek and surrounding hardwood forest. As a result, stands of timber have begun dying. There is potential interest in modifying infrastructure in this area to reduce the levels of inundation and restore natural flow to the area (Refuge staff, personal communication, 2016).

The magnitude and frequency of flooding on the Refuge seem to have increased in recent years and the climate analysis in this report suggests this will likely continue into the future. Statistical analysis of daily precipitation data from nearby Poplar Bluff, MO shows an increase in the annual number of high intensity precipitation events from 1893 to present (Section 3.4), and detailed analysis shows that high precipitation events are becoming more common and moderate precipitation events less common (Table 3.2) The USGS Hydrodynamic Climate Network Gage at the Current River near Van Buren, MO demonstrates an increase in both peak and average annual discharge over time, although the trend is not statistically significant. Temperature data for Poplar Bluff, MO suggests that average minimum temperatures in the area are increasing, while average maximum temperatures in the area are decreasing (Section 3.4).

Various water quality issues exist for the Refuge as well. With increased surface runoff, erosion and sediment transport are a major concern, as is the siltation of the Refuge's ditches and wetlands. Along with the sedimentation, there is potential for increased nutrient pollution, as well as agricultural chemicals, pesticides, and herbicides (Weber and Mosby 2010, Hundley 2013). In addition to these concerns, there are elevated levels of mercury found in soil, water, and organisms on the Refuge (Weber and Mosby 2010) The mercury levels are due to atmospheric mercury deposition rates in the Bootheel Region of Missouri, which are much higher than the national average. There are a number of studies examining the effects of mercury deposition on the Refuge and wildlife (Wood, 2007; Bruland, 1997; and Charboneau and Nash, 1993).

Pilot Knob National Wildlife Refuge

Pilot Knob National Wildlife Refuge is a 90-acre parcel of land located in the headwaters of the St. Francis River, near Ironton and Pilot Knob, MO. The Refuge lies almost entirely atop Pilot Knob, a small mountain 1,470 feet above sea level at its peak. Pilot Knob is an abandoned iron ore mine that was donated to the U.S. Fish and Wildlife Service by the Pilot Knob Iron Ore and Pellet Company in 1987 (USFWS 2007). The Refuge is currently closed to the public and serves to protect a significant population of the endangered Indiana Bat and the threatened Northern Long Eared Bat, which live in the abandoned mineshaft on the Refuge lands. A very small section of the East Branch of Knob Creek passes through the Refuge's boundaries, but for the most part, the Refuge does not have any significant water resources.

Ozark Cavefish National Wildlife Refuge

Ozark Cavefish Wildlife Refuge consists of two tracts of land located in Jasper and Newton Counties, Missouri. The Refuge was established specifically as habitat for the federally threatened, Ozark Cavefish. The tract of land in Newton County is a 40-acre parcel known as Turnback Cave, and is located on Turnback Creek adjacent to the MDC Paris Springs Conservation Area. The second tract of land is 1.7 acres in size and is located in Neosho, MO next to the Neosho National Fish Hatchery (NFH). This tract of land contains Hearrell Spring. The entire refuge is passively managed.

The Turnback Cave unit is located along the banks of Turnback Creek, a tributary of the Sac and Osage Rivers. It consists of a cave passage from which a groundwater spring flows into Turnback Creek. This unit contains water from both Turnback Creek as well as the Ozark Plateau Aquifer. Turnback Creek is a very flashy stream prone to large flooding events and is a 303(d) State-listed as impaired for Whole Body Contact Recreation river due to *E. coli* levels. The cave is primarily affected by groundwater in the area, and the cave's recharge zone has been delineated south and west of the Refuge itself (MDC 2005). Several roads and highways pass through the recharge zone, posing a risk to Ozark Cavefish through storm runoff, or accidental chemical spill (USFWS 2015).

The Hearrell Spring Unit is located 43 miles southwest of Turnback Cave and is in the Hickory Creek Watershed, which drains to the Spring and Neosho Rivers. The Spring is not directly affected by surface water from Hickory Creek, as the creek is the receiving body for the Spring's water. The Spring is one of three that are utilized by Neosho NFH as a water supply for spawning and raising fish. The Refuge Unit is located entirely within the city limits of Neosho. Its recharge zone, which extends southward is covered predominantly by residential areas, but also extends into the Fort Crowder Military Base (MDC 2011).

Both these Refuge Units are very sensitive to any pollution or environmental impacts and there are numerous studies suggesting that the Ozark Cavefish are sensitive to any mining operations in the nearby area or alterations to nutrient cycling in the caves or springs in which they live (Allert et al. 1997, Novinger et al, 2012).

1.2 Recommendations

Mingo National Wildlife Refuge

As outlined in section 1.1, the threats to Mingo NWR's water resources are as follows:

- Water quantity- prolonged flooding and insufficient drainage
- Water quantity- insufficient water supply in the fall during dry years
- Water quality- mercury
- Water quality- nutrients and agricultural runoff
- Infrastructure- siltation of ditches and water control structures
- Infrastructure- aging and/or sub-optimally designed water control structures that need replacement.
- Climate change- Increased surface water runoff, and increased heavy precipitation events.
- Land cover- Potential changes to the Mingo Basin outside of the Refuge's boundaries, such as increased agriculture, deforestation, or impervious surfaces.
- Invasive species-. Aquatic invasive species could potentially cause issues with the movement of water through the refuge or cause damage to existing water control infrastructure.

Below are Mingo NWR's water resource-related needs:

- Increased ability to mitigate water quantity extremes through increased drainage to manage for flood conditions or groundwater supplementation to manage for drought conditions
- Protect the Refuge's water quality by engagement and outreach to stakeholders and landowners in the upstream watersheds that surround the Refuge.
- Increased usage and integration of the water monitoring Arc Collector application.
- Model potential future restoration options including modifications to infrastructure at Monopoly Marsh, Mingo Creek, Molly's Curve, and Stanley Creek. This could involve collecting bathymetry for Mingo Creek
- An overall input/output water management model. This could involve either more real-time water level monitoring, or other methods such as quantifying rainfall-runoff relationships for all tributaries.
- Analyze and report all surface water gaging data collected on the Refuge, for both active and discontinued sites.
- Delineate and calculate drainage areas for all of the Refuge's tributaries using GIS analysis.
- Collect, Analyze and integrate historic bathymetry data for Monopoly Marsh and Rockhouse Marsh.
- Continuing to monitor for changes in elevated heavy metal contaminant levels.

Pilot Knob National Wildlife Refuge

As mentioned in section 1.1, Pilot Knob NWR does not have much in the way of water resources, however, *potential* threats are as follows:

- Excessive surface water runoff and erosion on refuge lands
- Contamination of water in the abandoned mineshaft

There are no known water resource related needs for Pilot Knob NWR at this time.

Ozark Cavefish National Wildlife Refuge

There are several threats to Ozark Cavefish NWR as mentioned in Section 1.1:

- Water quality- Pollution or contamination in the Refuge recharge zones
- Water quality- Mining operations and oil pipeline in areas around the Refuge
- Water quantity- Alterations to groundwater hydrology due to pumping for agriculture or industry
- Water quantity- Excessive flooding or erosion on Turnback Creek
- Public use- Illegal entry to Turnback Cave
- Climate change - Changes to groundwater temperature and/or quality due to climate change.

Several potential needs for Ozark Cavefish NWR include:

- Acquisition of, or conservation easements on, additional lands within the recharge zones to serve as a buffer to groundwater quality.
- Increase public education about the Ozark Cavefish and the effects of groundwater pollution in a karst system.
- Monitoring groundwater levels and water quality closer to the Refuge to identify any changes to groundwater supply or quality as they occur.

2. Introduction



Figure 2.1: Locations of National Wildlife Refuges in southern Missouri (USFWS 2007)

Mingo National Wildlife Refuge

Mingo NWR (MNWR) is located approximately 150 miles south of St. Louis, Missouri, in Stoddard and Wayne Counties just outside of Puxico, Missouri. Nearby landmarks and features include Wappapello Lake and the Mark Twain National Forest. The Refuge is located on the border between the Ozark Plateau and Lower Mississippi ecosystems and along the divide between the Upper and Lower St. Francis River basins.

The Refuge spans an area of 21,592 acres, including 15,000 acres of bottomland hardwood forest, which is the largest remaining contiguous tract of this habitat type in Missouri. Historically, there were over 2.5 million acres of bottomland hardwood forest found in the Lower Mississippi Basin. The Refuge also contains 3,500 acres of marsh and open water, 411 acres of cropland, 704 acres of moist soil units, and 474 acres of grassy openings (FWS 2007). Within the Refuge there is also a designated Wilderness Area consisting of 7,730 acres, which was established in 1976 through the National Wilderness Act. Also, there are seven Research Natural Areas that combined cover 625 acres (FWS 2011).

Mingo NWR was established in 1944 by the Migratory Bird Conservation Commission through the Migratory Bird Conservation Act. The area that is currently Mingo NWR was mostly uninhabited until 1870-1880, when the logging industry was drawn to the area for its old growth cypress and tupelo trees. The area was nearly completely logged over by the 1930s. In 1914, the Mingo Drainage District was formed and \$1 million was used to make the great Mingo Swamp suitable for farming purposes through drainage ditches and water control measures. However, due to flooding from the St. Francis, unproductive soils, and the Great Depression, the drainage district went bankrupt. After that time, the land was used freely by local citizens without regard for conservation. Until the federal government acquired this land, indiscriminate grazing, burning, and hunting were common practices (Heitmeyer et al. 2006).

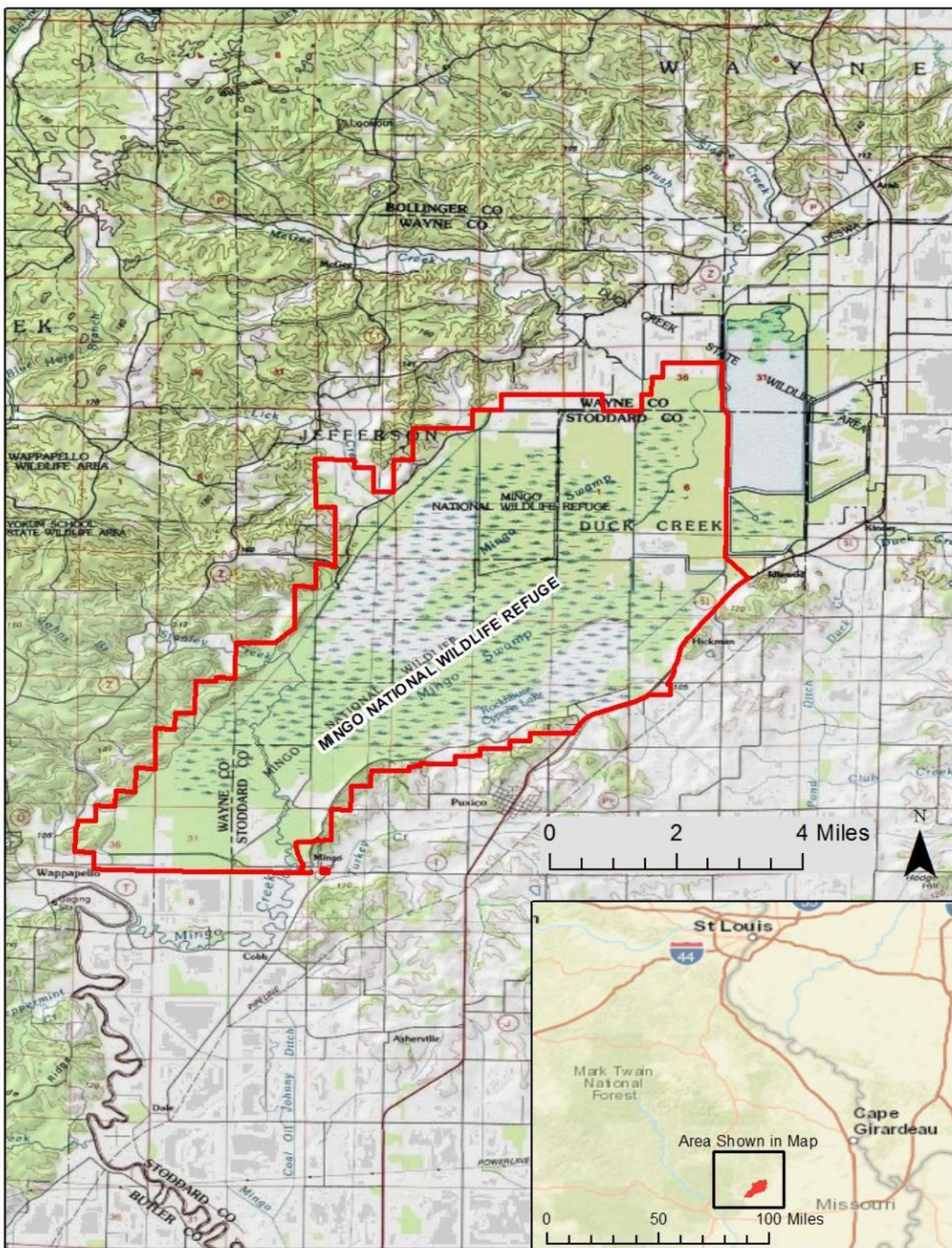


Figure 2.2: Reference map of Mingo NWR

Pilot Knob National Wildlife Refuge

Pilot Knob National Wildlife Refuge (PKNWR) is a 90-acre parcel of land located at the top of Pilot Knob Mountain in Iron County, Missouri. Located between the towns of Ironton and Pilot Knob, the Refuge lies approximately 75 miles northeast of Mingo NWR and 70 miles south of St. Louis, Missouri. Pilot Knob NWR is not currently open to the public and serves primarily to protect the endangered Indiana Bat (*Myotis sodalis*) (USFWS 2007). It was estimated that at one time, the abandoned mine shafts at the top of the mountain were utilized by 1/3 of the entire Indiana Bat population for hibernation (USFWS 2007). The Pilot Knob Ore and Pellet Company donated the property to the Fish and Wildlife Service in 1987. The mine was active until the 1950s and utilized iron oxide, which does not have as many toxic byproducts as the more common iron sulfide (Mense and Kudma, personal communication 2016). Pilot Knob NWR is located in the Ozark Plateau at the headwaters of the St. Francis River with a very small portion of the East Branch of Knob Creek passing through its boundaries.

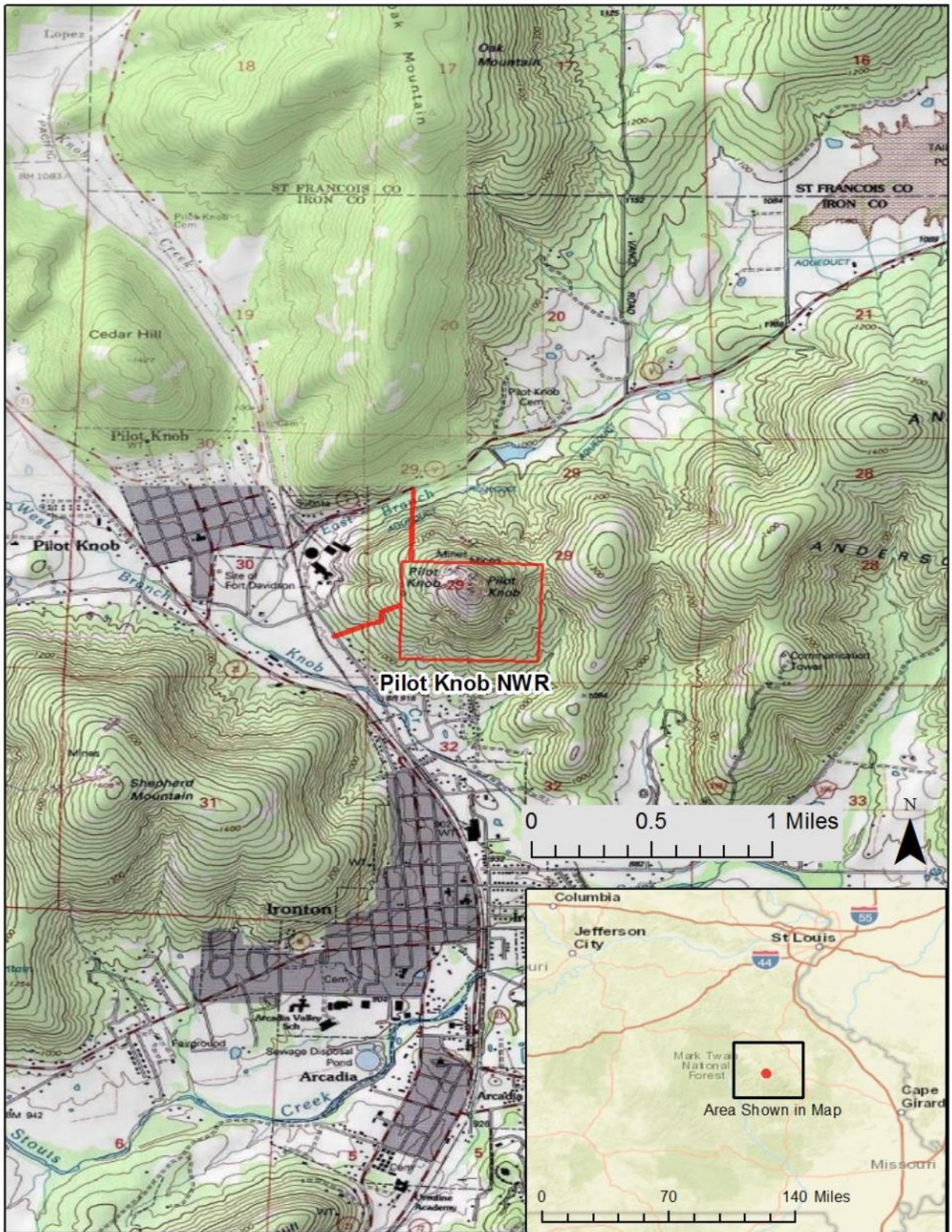


Figure 2.3: Reference map of Pilot Knob NWR

Ozark Cavefish National Wildlife Refuge

Ozark Cavefish National Wildlife Refuge (OCNWR) was established in 1991 through the National Endangered Species Act. It covers 2 of only 20 known caves in the world to contain the endangered Ozark Cavefish (*Amblyopsis rosae*) (USFWS 2015). The refuge exists as two units separated by 43 miles in Lawrence and Newton Counties in southwest Missouri. The largest parcel is the Turnback Cave Unit and is located approximately 20 miles east of Springfield near the town of Mt. Vernon, Missouri. This unit consists of a 40-acre parcel on Turnback Creek, a tributary of the Sac River. The Refuge directly adjoins the 208-acre Paris Springs Conservation Area, which has three entrances to Turnback Cave, but the cave's exit to Turnback Creek is located on USFWS land along with approximately 3,000 feet of interconnected passages. Turnback Cave is a highly diverse cave known to contain Ozark Cavefish, Gray Bat, Bristly Crayfish, and other rare cave species (USFWS 2015). The second unit is a 1.3-acre parcel in Neosho, Missouri that directly adjoins the Neosho National Fish Hatchery (NFH). Neosho is located approximately 65 miles southwest of Springfield, Missouri and 100 miles northeast of Tulsa, Oklahoma. This small tract of land contains Hearrell Spring, which is one of three groundwater springs that provide two million gallons of water per day for Neosho NFH (USFWS 2015).

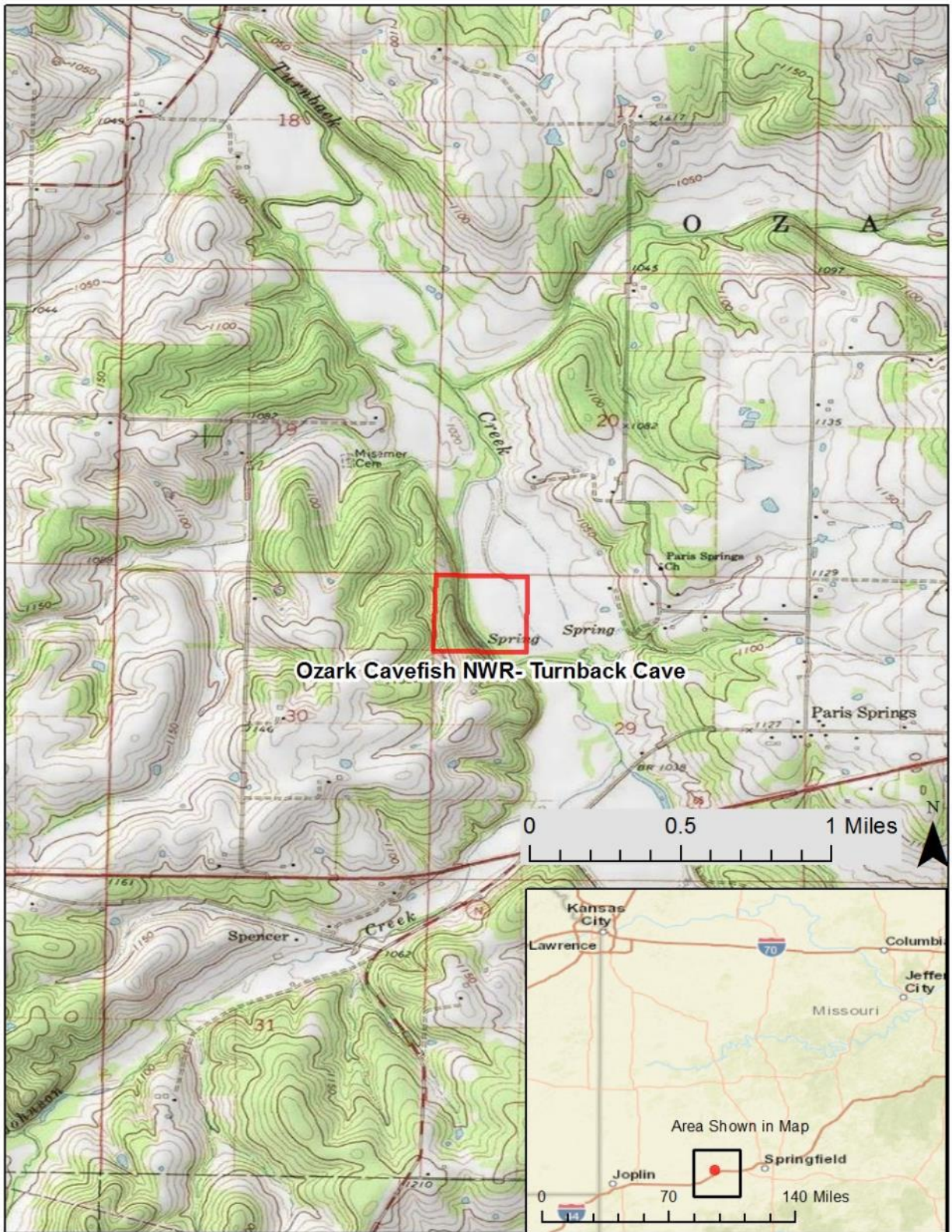


Figure 2.4: Reference map of Ozark Cavefish NWR- Turnback Cave Unit

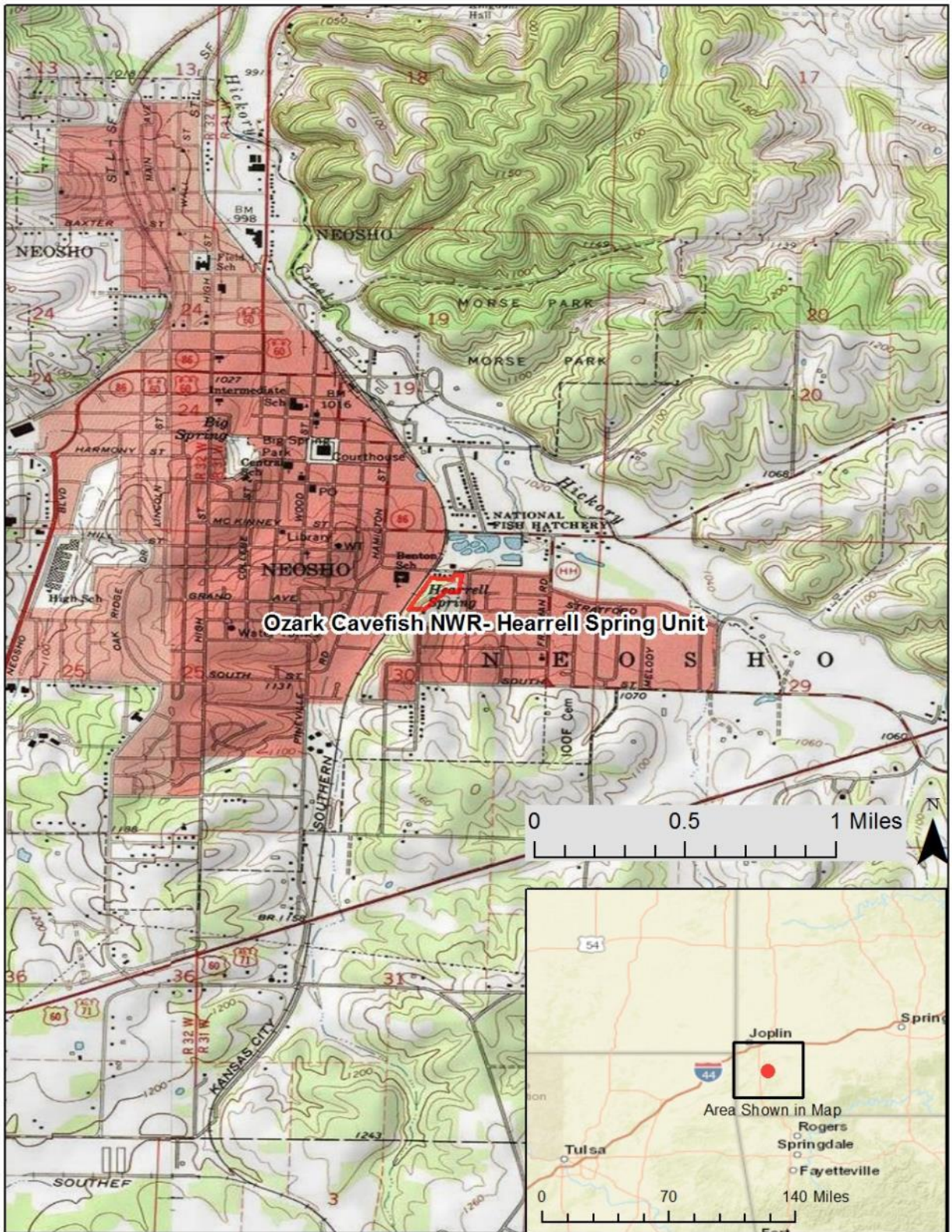


Figure 2.5: Reference map of Ozark Cavefish National Wildlife Refuge- Hearrell Spring Unit

3. Natural Setting

The natural setting section describes the abiotic resources associated with the Refuge, including relevant watershed boundaries, topography, and climate. These underlying, non-living components of an ecosystem provide the context on which water resources are based and managed. Many of these elements are also described in the CCP (USFWS 2011).

3.1 Hydrologic Unit Codes (HUCs)

Hydrologic information can be described in the context of a refuge's designated Region of Hydrologic Influence (RHI), which is the relevant region for the collection of water quality and quantity information. For the purposes of the WRIA, Hydrologic Unit Code (HUC) boundaries, part of the USGS Watershed Boundary Dataset, are often used as a general framework to designate RHIs. HUCs designate watersheds of various sizes and often represent the initial aggregate level of water quality and quantity information available from a variety of agencies. HUC boundaries are a successively smaller classification system based on drainage, adapted from Seaber et al. (1987). A list of relevant HUC-8s, HUC-10s, and the smaller HUC-12 boundaries are provided for each refuge below.

Mingo National Wildlife Refuge

Mingo NWR's RHI falls within the Lower St. Francis River 8-digit HUC (HUC-8) watershed. It is located at the northern edge of this watershed and closely borders both the Upper St. Francis River and Castor River HUC-8 watersheds. However, these two HUC-8's sometimes influence the hydrology of the Refuge itself. The Castor River floods onto Refuge land several times per year, and the St. Francis River can potentially cause a hydrologic dam causing backwater on the Mingo Ditch (Refuge staff, personal communication, 2016). For the purposes of the RHI, only the main contributing drainage was considered. MNWR is located entirely within Mingo Swamp HUC-10 and Mingo Swamp HUC-12 subwatersheds, and it receives direct input from the McGee Creek and Brush Creek HUC-12s to the north. The Refuge boundaries encompass approximately 40% of the entire Mingo Swamp HUC-12 and 27% of the Mingo Swamp HUC-10.

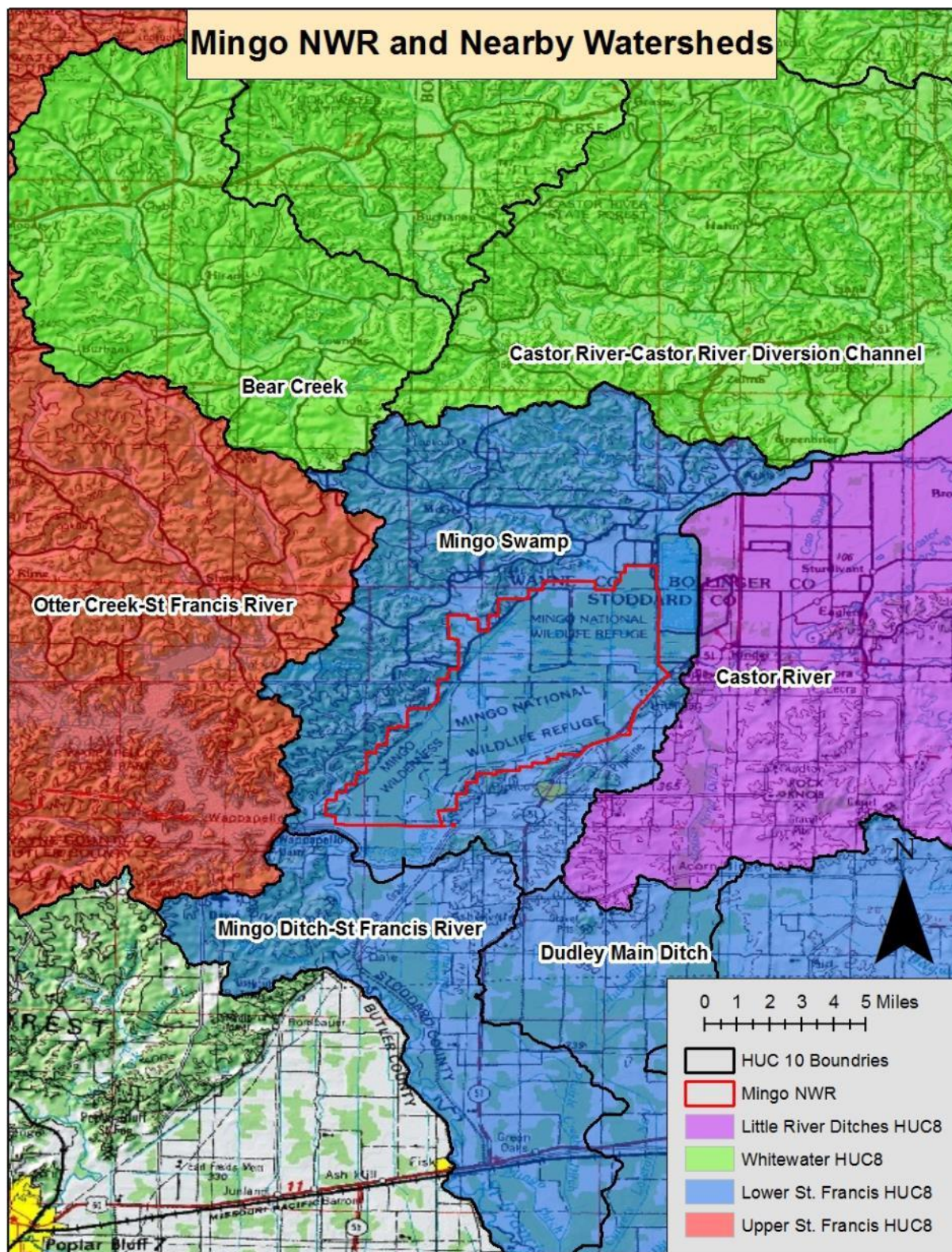


Figure 3.1: Position of Mingo NWR in relation to local major watersheds

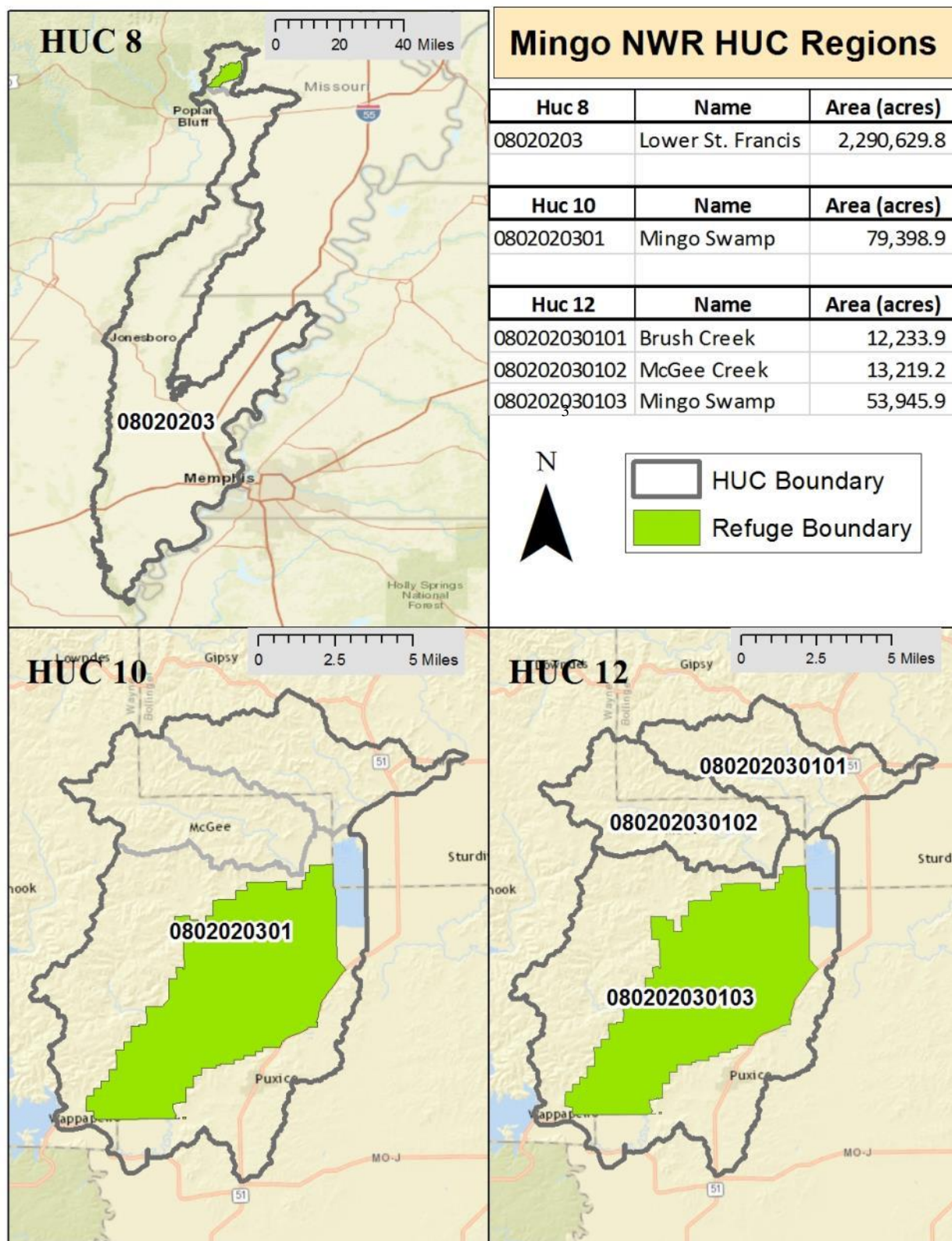


Figure 3.2: Map of Mingo NWR HUC regions

Pilot Knob National Wildlife Refuge

Pilot Knob NWR's RHI is located in the headwaters of the Upper St. Francis River HUC-8, over 70 miles upstream of Mingo NWR and Wappapello Lake. The Refuge is also located in the Stouts Creek/St. Francis HUC-10, and within the Stout Creek Headwaters HUC-12. However it is in close proximity to the Stout Creek HUC-12 and may be partially linked to the Wachita Creek/St. Francis HUC-12 by way of artificial aqueduct (see Section 4.3). The RHI of this particular Refuge is quite limited due to its topographic elevation. Only a small portion of Knob Creek (in the Stouts Creek Headwaters HUC-12) passes through the Refuge's boundaries. The Refuge likely serves mainly as a source of surface runoff and groundwater recharge to the region, and is not directly affected by nearby waterbodies.

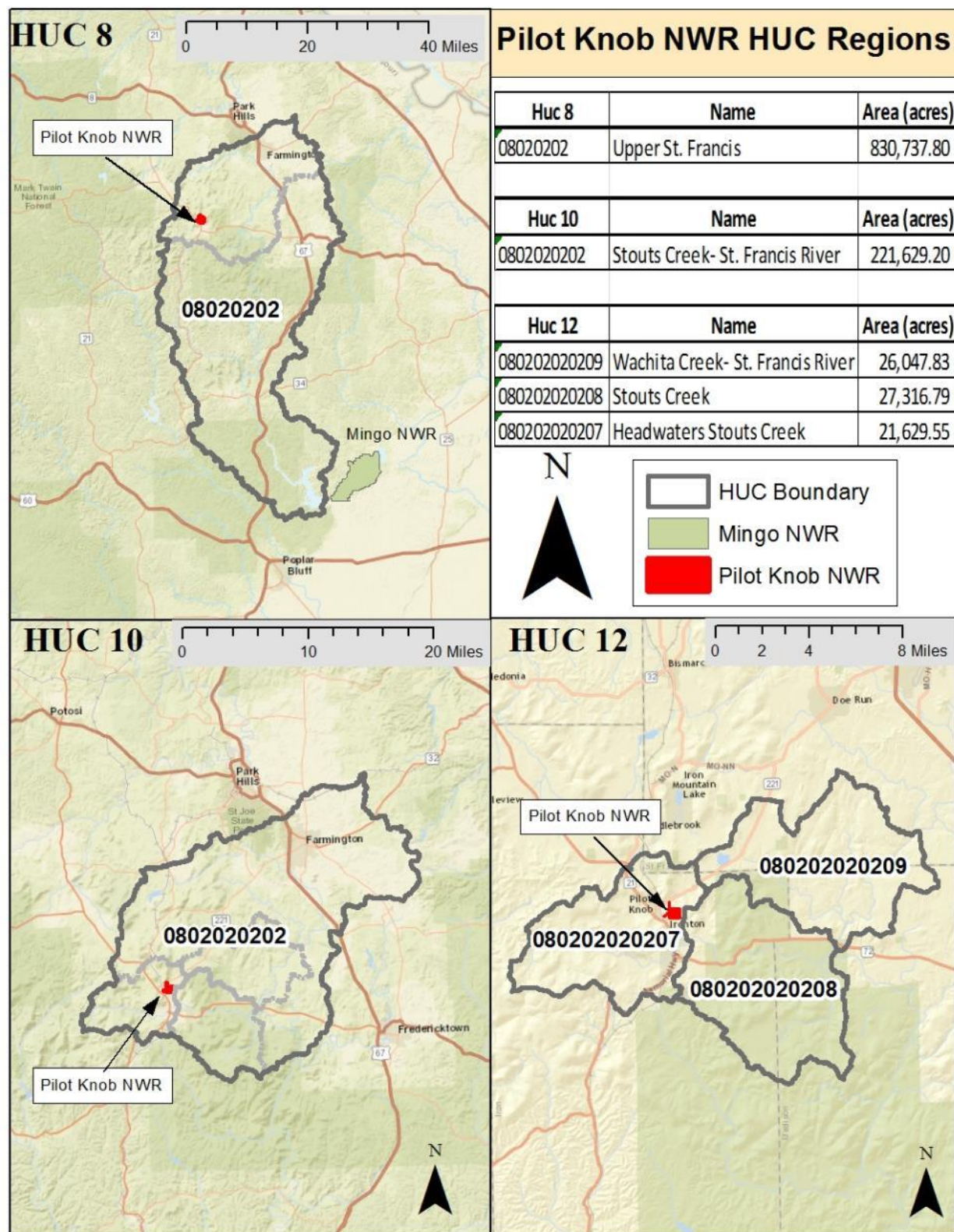


Figure 3.3: Map of Pilot Knob NWR HUC regions

Ozark Cavefish National Wildlife Refuge

OCNWR has two different surface water Regions of Hydrologic Influence. Turnback Cave's RHI is located within Sac River HUC-8. The Sac River is a tributary of the Osage River, which in turn flows to the Missouri River. The unit falls within the Turnback Creek HUC-10, and the Billie Creek/Turnback Creek HUC-12. Also, Goose Creek and Turnback Creek Headwaters HUC-12s are just upstream of the site, and strongly influence its hydrology. Hearrell Spring's RHI is within the Spring River HUC-8 watershed. The Spring River is a tributary of the Neosho River, which in turn flows into the Arkansas River. Within this HUC-8, Hearrell Spring falls within the Shoal Creek HUC-10 and the Hickory Creek HUC-12. The waters from the spring itself flow through Neosho NFH and are received by Hickory Creek.

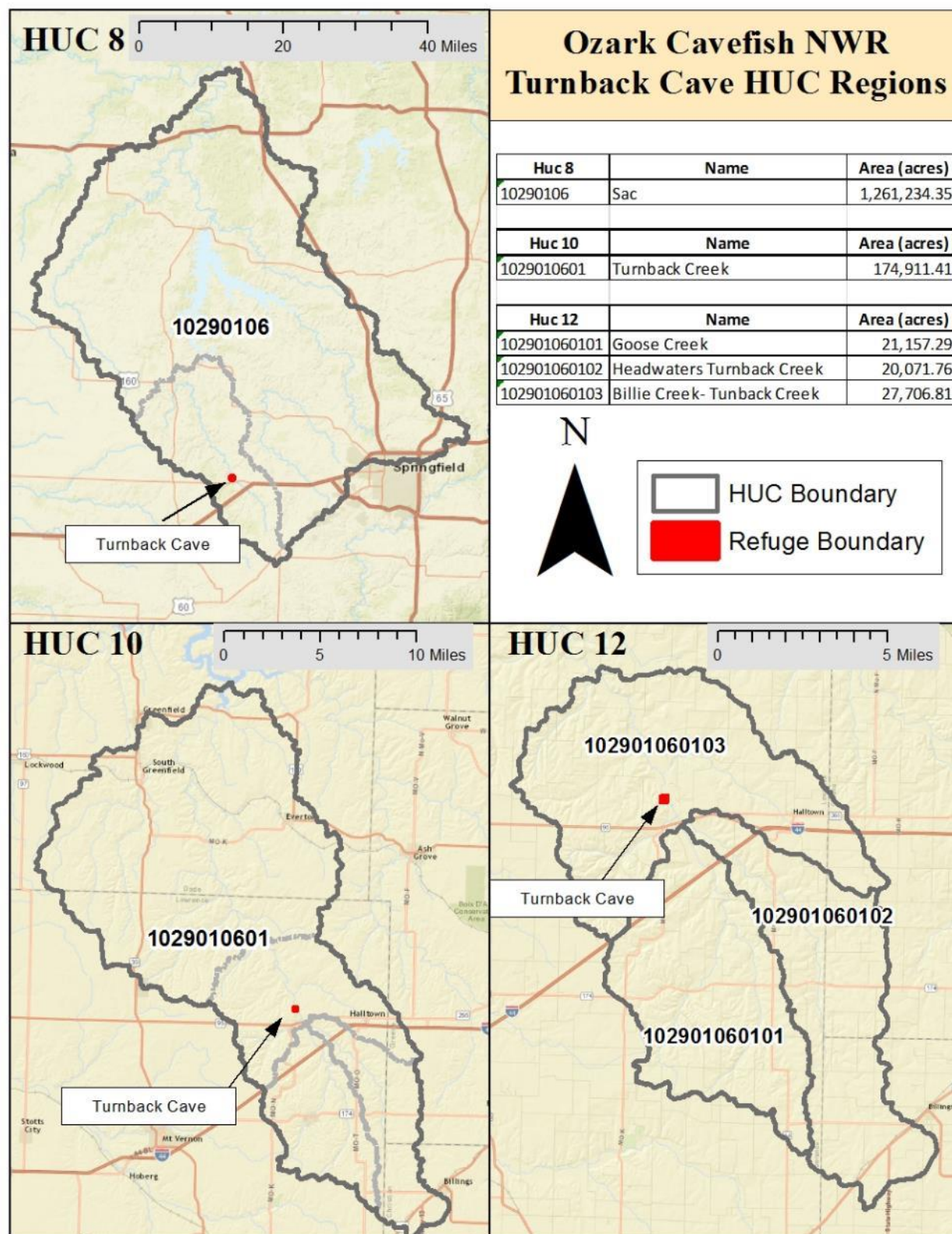


Figure 3.4: Map of Ozark Cavefish National Wildlife Refuge- Turnback Cave unit HUC regions

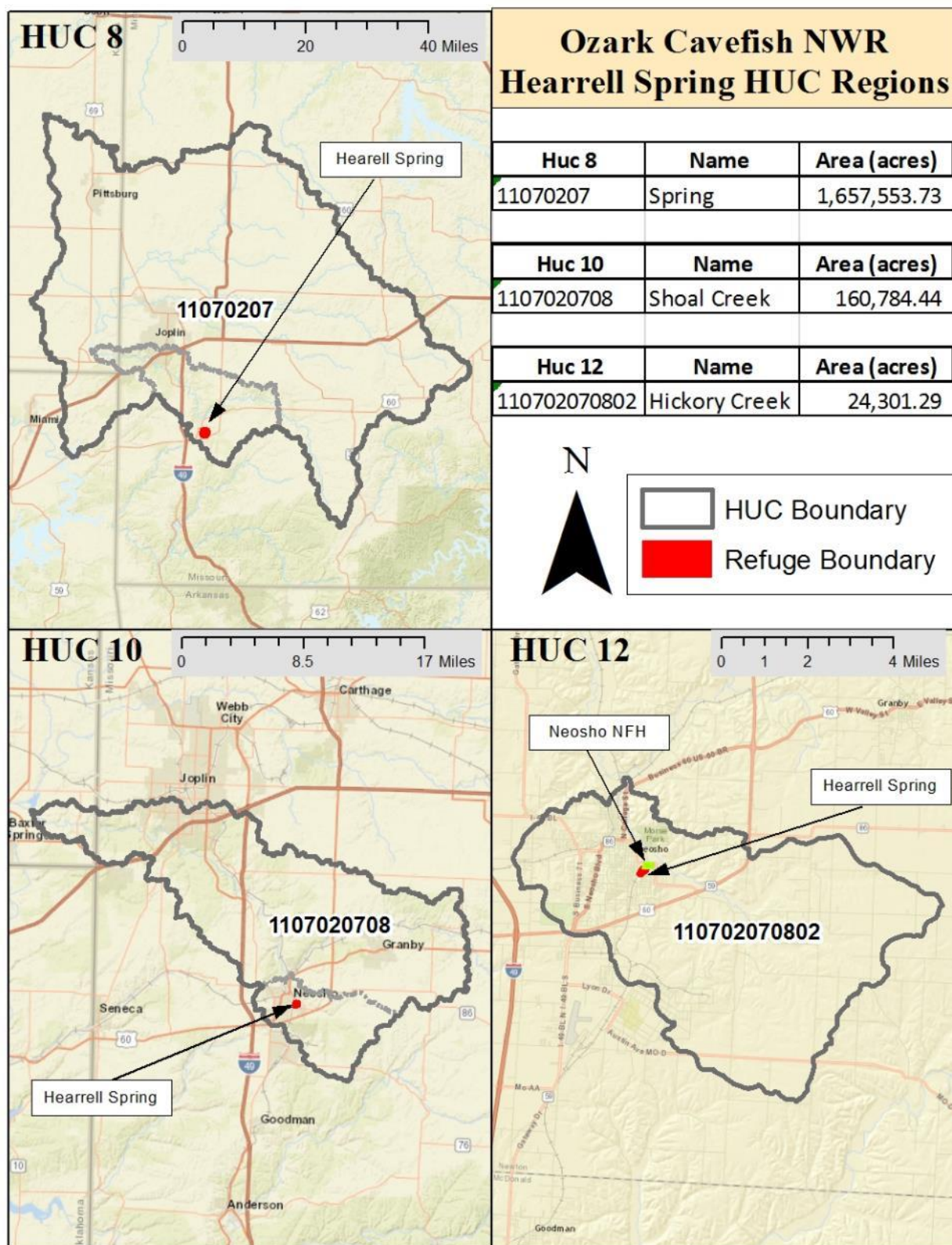


Figure 3.5: Figure of Ozark Cavefish National Wildlife Refuge- Hearrell Spring unit HUC regions

3.2 Ozark Cavefish NWR Groundwater RHI

While surface water influences undoubtedly play a role in the hydrology of the Ozark Cavefish, the refuge's two units are even more closely linked with the groundwater hydrology of the local area. Both units of OCNWR fall within the Ozark Plateau Aquifer System, which covers most of southern Missouri as well as parts of Oklahoma, Arkansas, and Illinois. Within the Ozark Aquifer, both units are within Missouri's Springfield Plateau Groundwater Province (Figure 3.6). Turnback Cave in Lawrence county lies to the north and Hearrell Spring in Newton County lies to the west of this high point. Assuming flow from areas of high elevation head to areas of low elevation, groundwater would flow from the southwest towards Turnback Cave and from the east and south towards Hearrell Spring (Figure 3.7). In 2005 and 2011 delineations of OCNWR's recharge zones were performed by Ozark Underground Laboratories under direction of the Missouri Department of Conservation. Turnback Cave's recharge zone falls to the south and west of the cave in Lawrence County (Figure 3.8) (MDC 2005), and its borders closely follow that of the Goose Creek HUC-12 (Figure 3.4). The Hearrell Spring recharge zone lies directly south of the Refuge towards the higher elevation lands south of Neosho (Figure 3.9)(MDC 2011). This recharge zone actually extends beyond the drainage divide for the Spring River HUC-8 (Figure 3.4).

For springs such as Hearrell Spring or Turnback Cave, the local groundwater hydraulic gradient can account for up to 80% of the overall flow, greatly buffering the impacts of sharp rainfall pulses. The range of minimum to maximum flows in most Ozark Aquifer Springs ranges between 1.5x to 4.5x, whereas surface water streams range between 10x and 4000x (Criss 2009). Ozark Cavefish have been found to occupy a much greater range in a given aquifer than just the spring in which they are sighted. As such it is recommended that protection of the fish should extend to the entire aquifer or recharge zone as opposed to a single spring or cave. (Means and Johnson 2005).

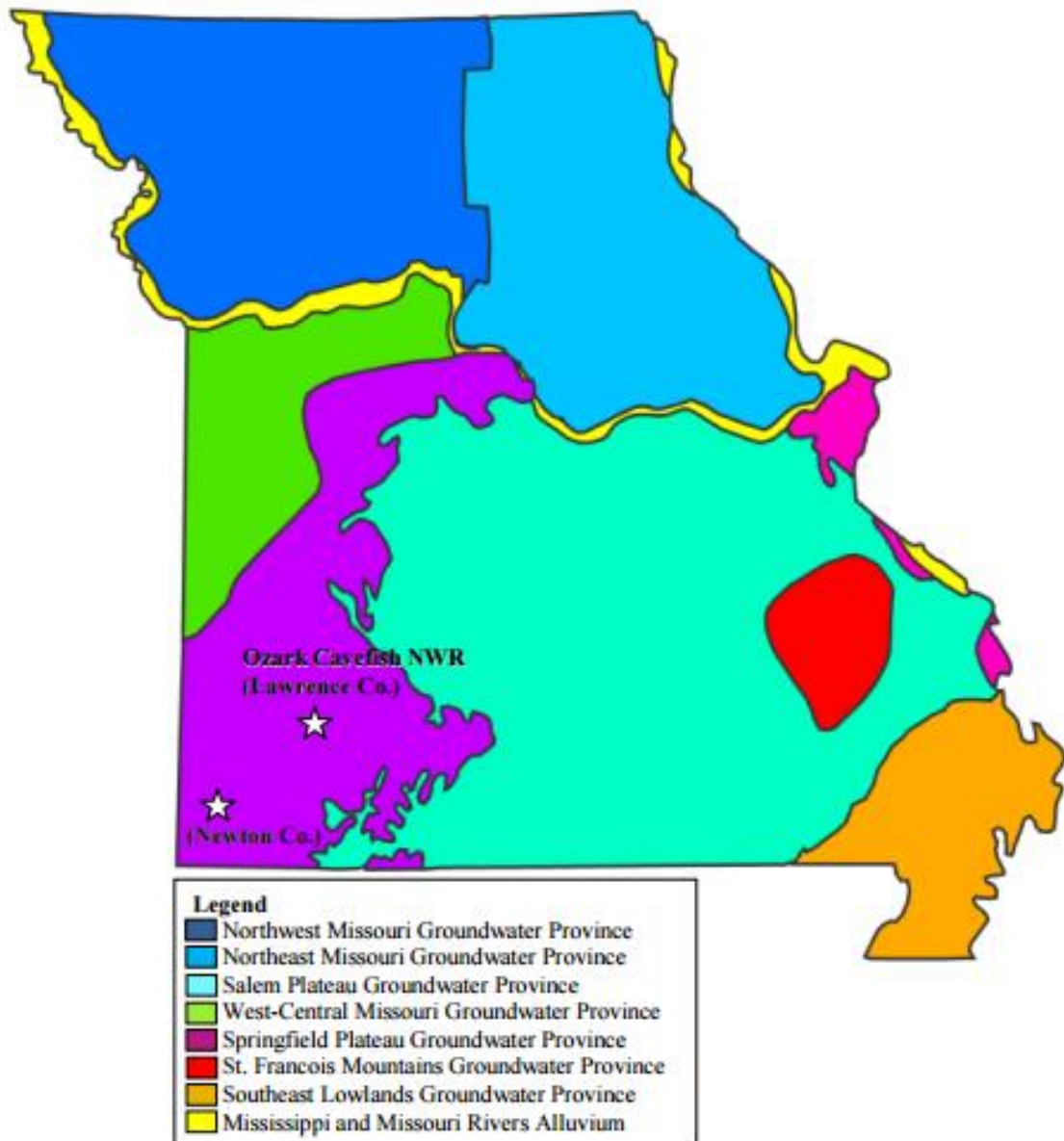


Figure 3.6: Map of Groundwater Provinces in Missouri (USFWS 2015)

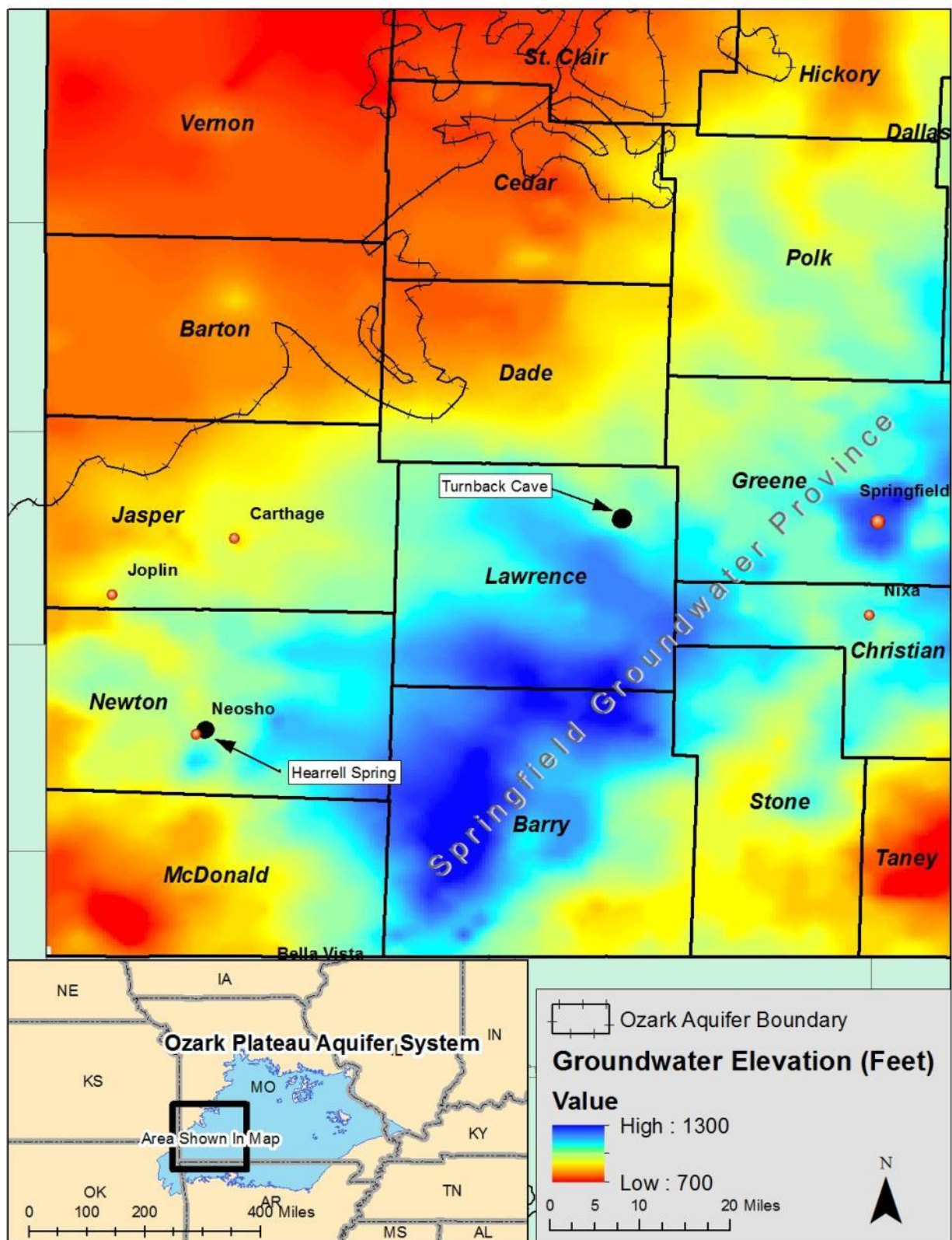


Figure 3.7: Map of groundwater elevations in the area surrounding OCNWR

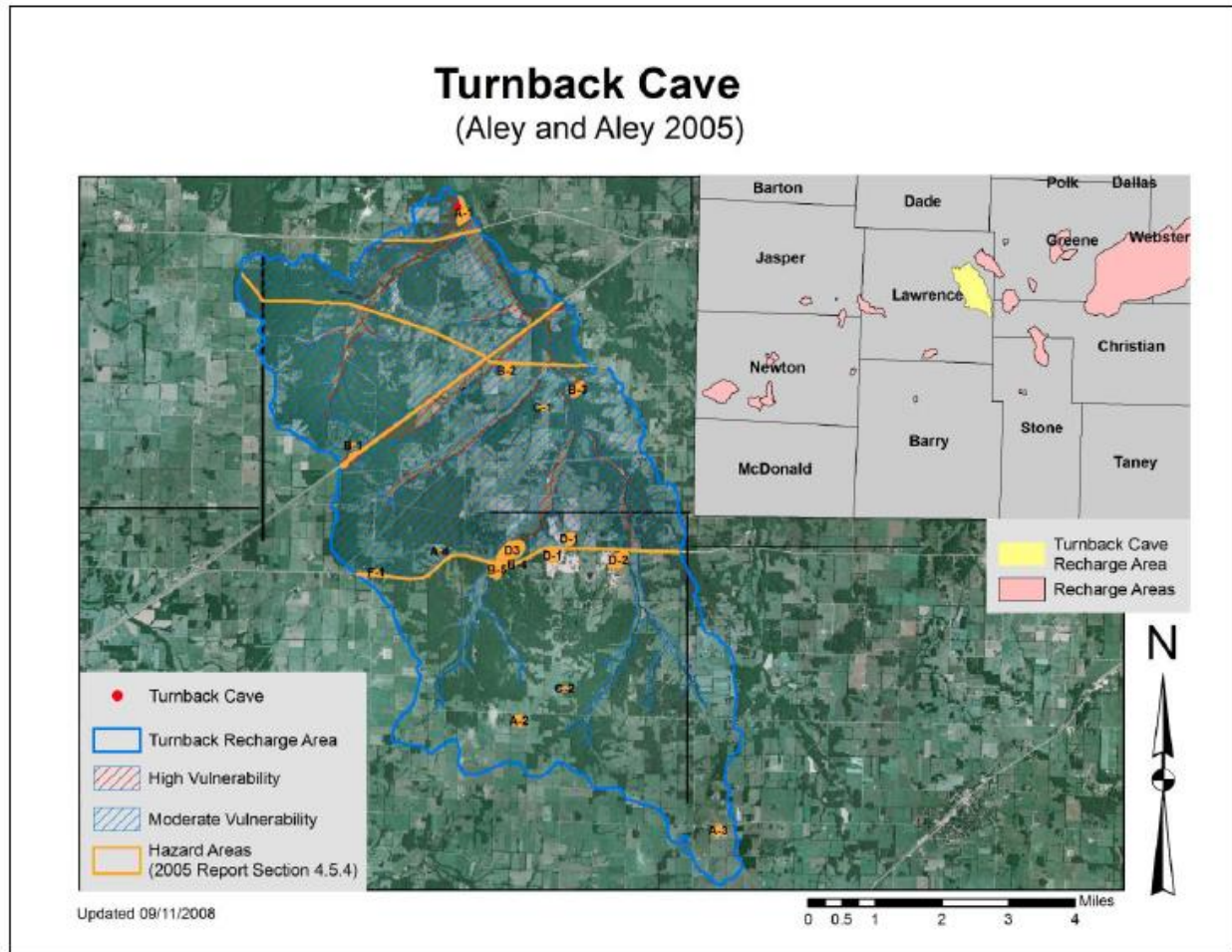


Figure 3.8: Map of Turnback Cave recharge area (MDC 2005).

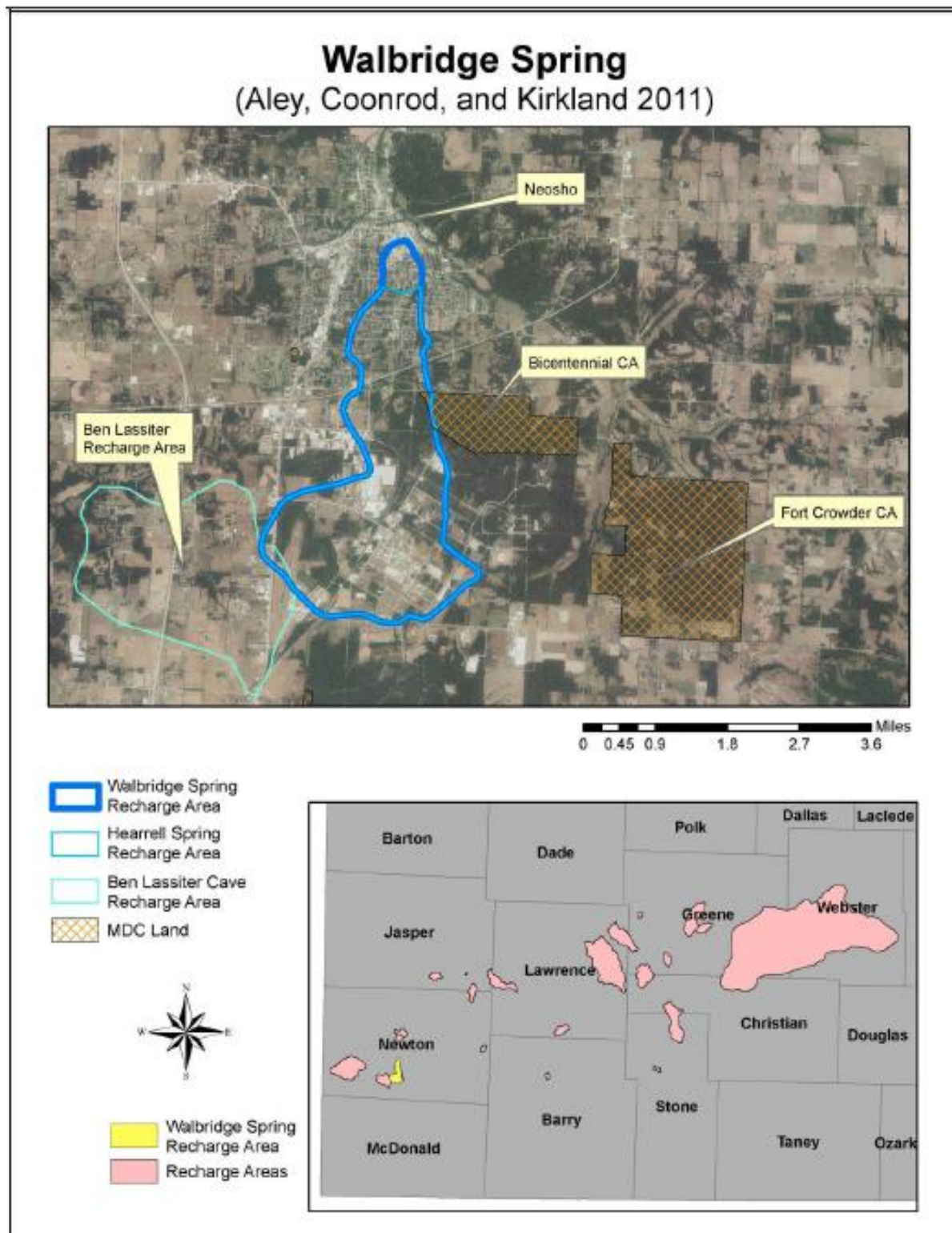


Figure 3.9: Map of Walbridge Spring recharge area, including Hearrell Spring recharge area (MDC 2011)

3.3 Topography

High resolution (1-meter) bare-earth LiDAR data is currently available for Mingo NWR's property units (NAVD88) from the U.S. Army Corps of Engineers (collected in 2009). This LiDAR was processed and combined with bathymetric surveys performed by Refuge Staff (Figure 3.10). However, there is no LiDAR available for either Pilot Knob NWR or Ozark Cavefish NWR at the time of this report. The Status of LiDAR in Lawrence and Newton Counties is pending and should be completed in the near future; however most of Iron County, including Pilot Knob NWR is not scheduled for completion anytime soon (MSDIS 2016). Topography data for PKNWR and OCNWR (Figures 3.12-3.14) was obtained from USGS's National Elevation Dataset (NED) 1/3 Arc Second DEM (http://nationalmap.gov/3dep_prodserv.html).

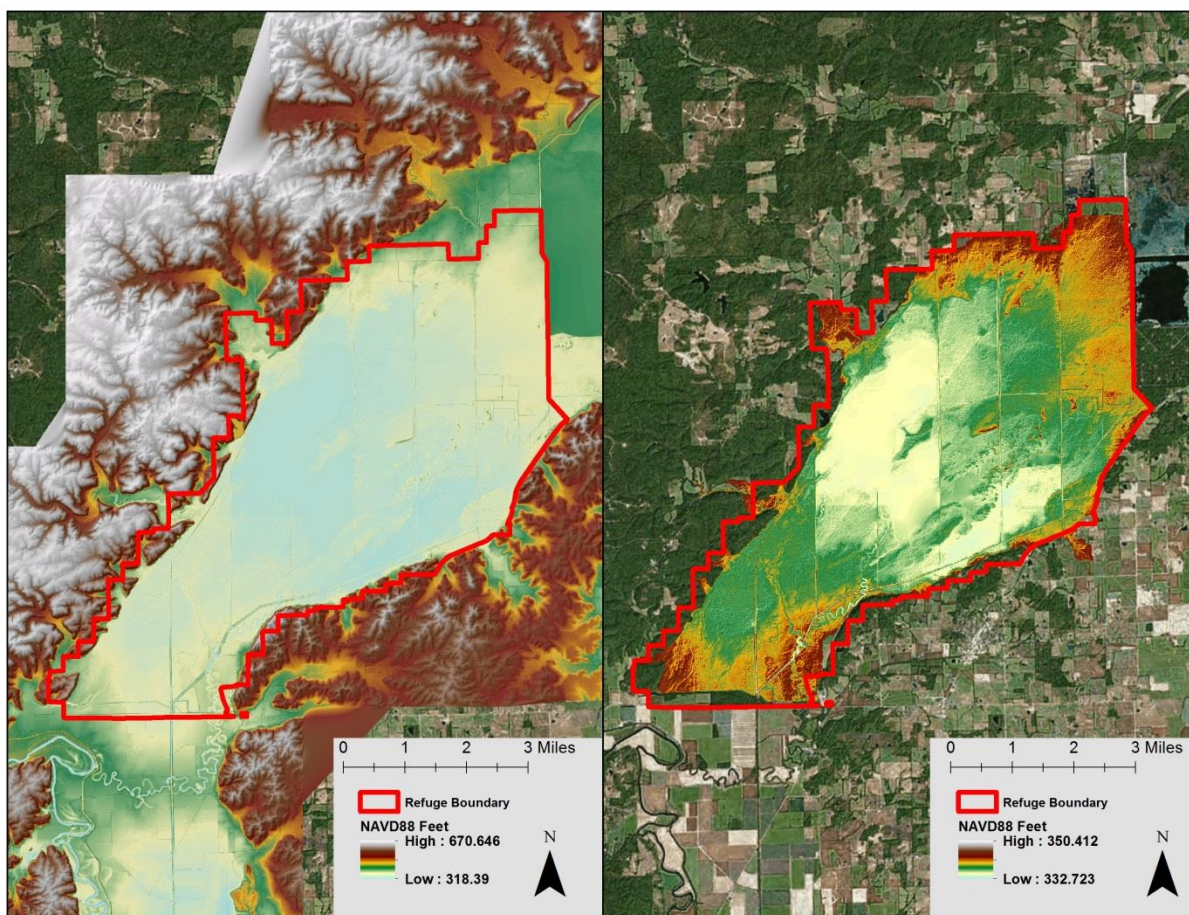


Figure 3.10: DEM (LIDAR) of Mingo NWR and surrounding area (left) and for only areas below 350 feet NAVD88

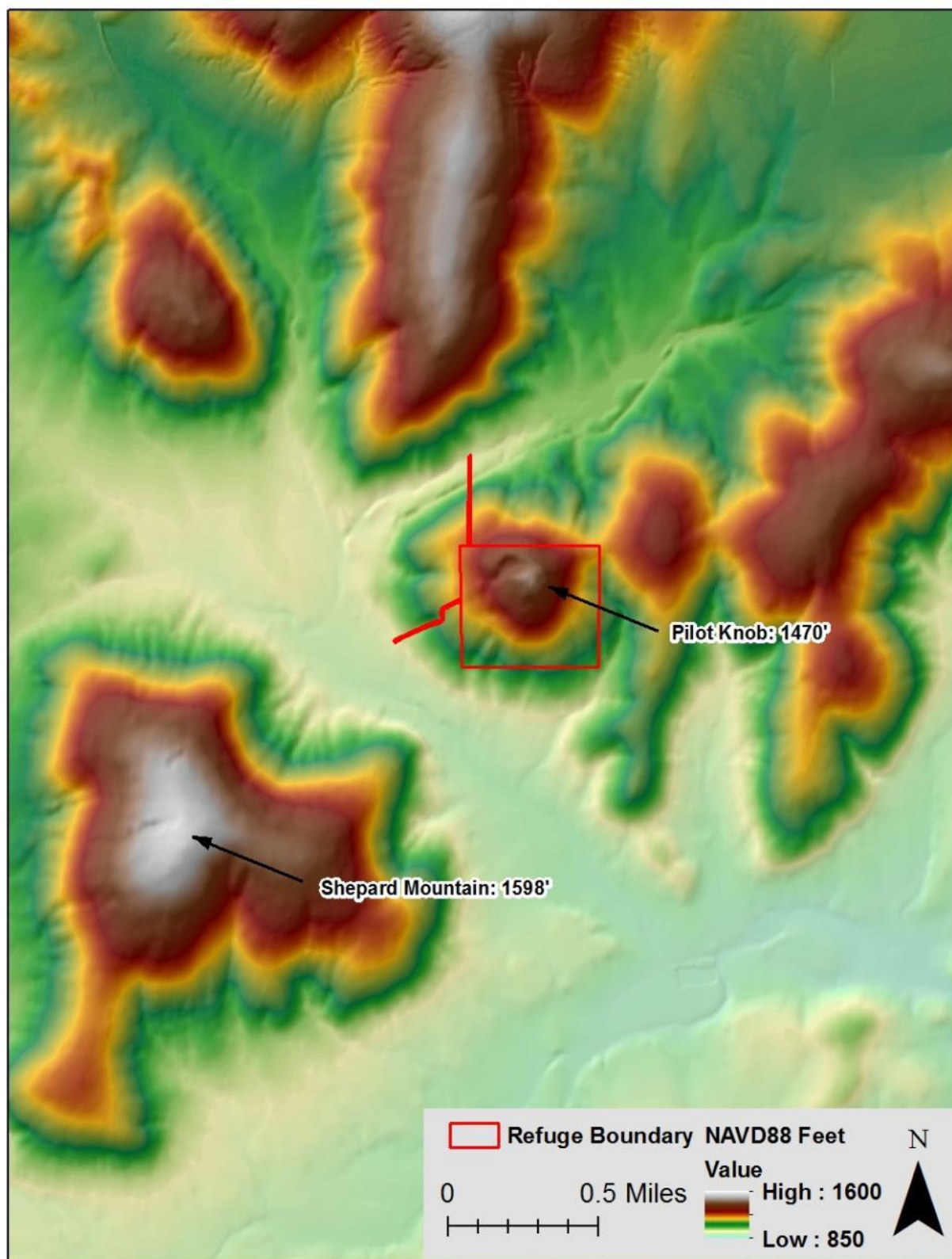


Figure 3.12: DEM (National Elevation Dataset) of Pilot Knob NWR and surrounding area

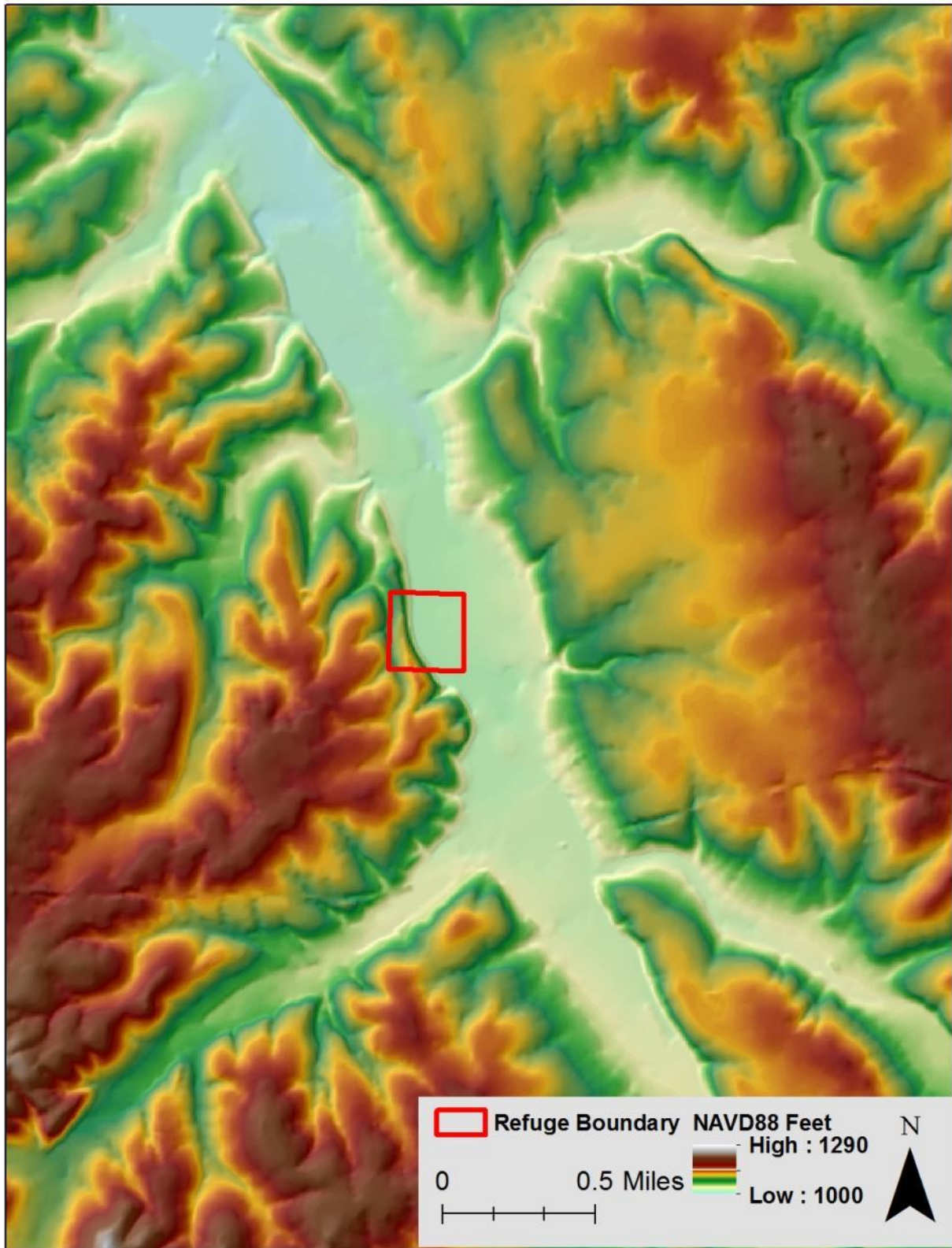


Figure 3.13: DEM (National Elevation Dataset) of OCNWR- Turnback Cave Unit and surrounding area

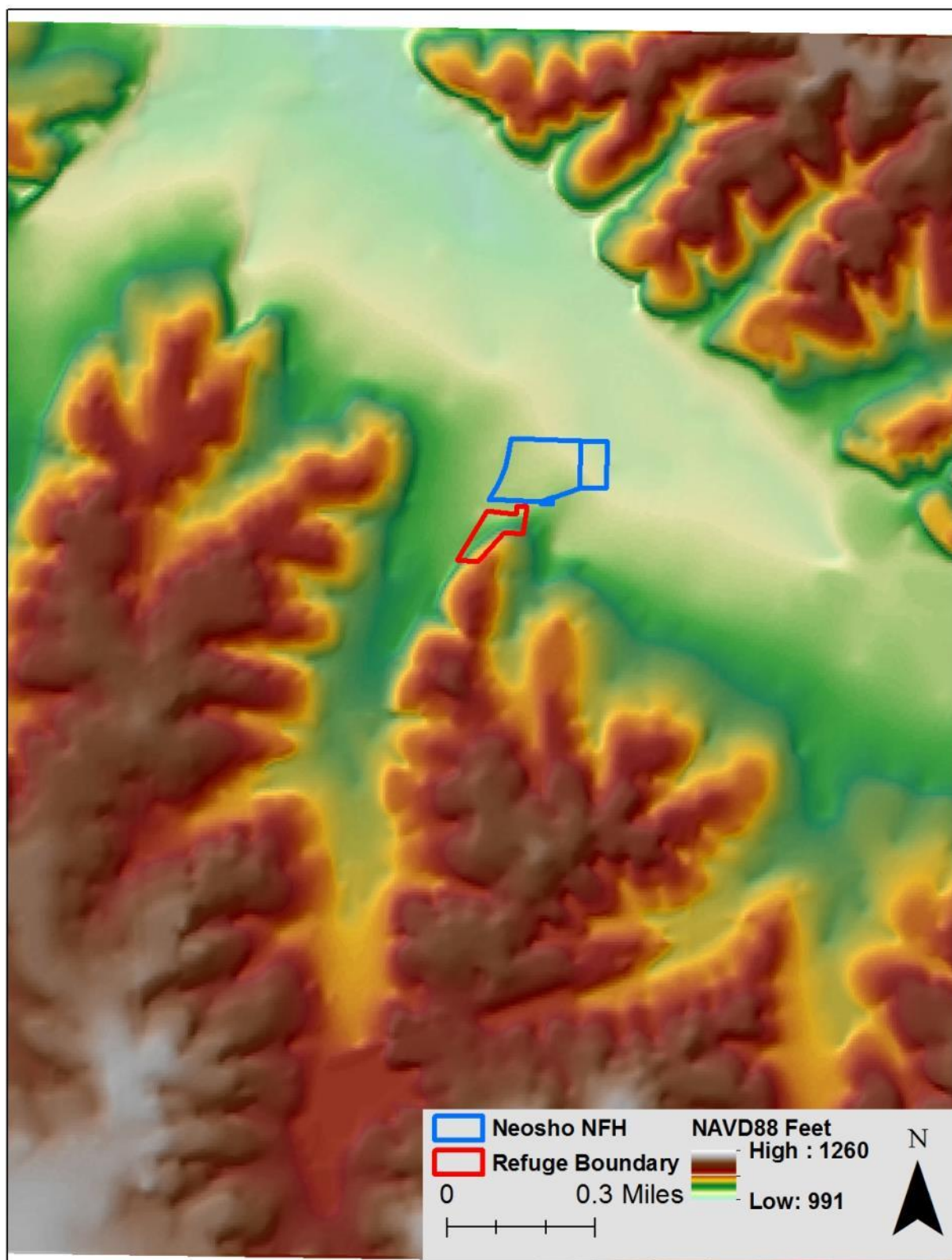


Figure 3.14: DEM (National Elevation Dataset) of OCNWR- Hearrell Spring Unit and surrounding area

3.4 Historic and Long-Term Climate Trends

Executive Order 13653 (2013) calls for “strengthened resilience to climate change impacts.” Agencies are instructed to prepare for climate change effects that will continue to be felt—by revising policies and programs appropriately, and specifically to identify alterations to be made to land and water-related regulations and programs. Executive Order 13653 directs agencies to encourage the function of natural storm buffers, such as wetlands, and to provide relevant information about climate change to the public so decisions can be made with careful consideration for future impacts. Additionally, agencies need to develop and implement procedures for the identification and management of the most serious threats.

The WRIA provides a preliminary broad-based analysis of trends and patterns in precipitation and temperature. Climate is defined here as the typical precipitation and temperature conditions for a given location over years or decades. These types of trends and patterns affect groundwater levels, river runoff, and flooding regularity and extent. This section evaluates Mingo, Pilot Knob, and Ozark Cavefish’s current and historical climate patterns by:

- discussing the current climate and changes already experienced in the region
- briefly summarizing projections for the future from selected models
- analyzing Parameter-elevation Relationships on Independent Slopes Model (PRISM) and U.S. Historical Climatology Network (USHCN) datasets
- analyzing changes in the regional hydroclimate and identifying hydrologic implications by evaluating a relevant dataset from the USGS- Hydroclimatic Data Network (HCDN)

Historical climate conditions

Mingo National Wildlife Refuge

The climate of the region surrounding Mingo NWR is characterized as continental, with variable temperatures throughout all months of the year. The CCP describes average temperatures and precipitation based on climate data from the Stoddard County Soil Survey (USFWS 2007):

“Long, hot summers and rather cool winters characterize the climate of the Refuge and surrounding area. An occasional cold wave brings near freezing or subfreezing temperatures but seldom much snow. Precipitation is fairly heavy throughout the year, and prolonged droughts are rare. Summer precipitation falls mainly in the form of afternoon thunderstorms. In winter the average temperature is 37 degrees Fahrenheit, and the average daily minimum temperature is 28 degrees. In summer the average daily temperature is 78 degrees, and the average daily maximum temperature is 90 degrees. Total annual precipitation is 48 inches. Of this, about 25 inches, or 50 percent, usually falls between April and September.”

The Refuge is shown to have a low sensitivity to climate change because it is not located near the edges of the biome and contains little critical habitat for threatened and endangered species (Magness et al. 2011). Mingo NWR also exhibits a low adaptive capacity because it covers a small latitude range and only 3% of the watershed is protected. The density

of roads in the watershed is greater than 12 m/ha, so any regional climatic changes experienced in the future could be especially damaging to the Refuge and the wildlife it is intended to protect (Magness et al. 2011).

Pilot Knob National Wildlife Refuge

The climate of Pilot Knob NWR is different than that of Mingo NWR due to its location entirely within the higher elevation Ozark Plateau region of Missouri. Average temperatures are cooler and the growing season is shorter. Annual precipitation is also much less. The Mingo NWR CCP describes Pilot Knob's climate as follows (USFWS 2007):

"The climate of the Refuge is humid continental with warm summers and cool winters. Mean annual temperature of Iron County is 56 degrees Fahrenheit (F) with a mean January temperature of 32 degrees F and a mean July temperature of 73 degrees F. Mean annual precipitation is 44.3 inches and is rather evenly distributed throughout the year with an average of 3.7 inches per month."

The Refuge is noted to have a low sensitivity to climate change because it is not located near the edges of the biome and contains little critical habitat for threatened and endangered species (Magness et al. 2011). However, Magness et al. 2011 is mistaken for presuming the Refuge does not contain critical habitat for endangered species. As previously mentioned, the Refuge was established for the preservation of critical habitat for the federally listed endangered species, the Indiana Bat (USFWS 2007). When this is taken into account, the Magness et al. 2011 model still yields the same low sensitivity result.

Ozark Cavefish National Wildlife Refuge

Ozark Cavefish NWR's climate is complicated somewhat by the fact that it is composed of two distinct units separated by a fair distance. The Ozark Cavefish HMP (USFWS 2015) describes the Refuge's climate as follows:

"The climate of Lawrence and Newton Counties is a humid continental type with warm summers and cool winters. Mean annual temperature of Lawrence County is 56.49 F with a mean January temperature of 32.6 F and a mean July temperature of 78.3 F. Rainfall is fairly heavy with mean annual precipitation of 45.93 inches and is rather evenly distributed throughout the year with an average of 3.8 inches per month. Mean annual temperature of Newton County is 57.2 F with a mean January temperature of 33.5 F and a mean July temperature of 78.8 F. Rainfall is fairly heavy with mean annual precipitation of 45.54 inches and is rather evenly distributed throughout the year with an average of 3.8 inches per month."

The Refuge is noted to have a low sensitivity to climate change because it is not located near the edges of the biome and contains little critical habitat for threatened and endangered species (Magness et al. 2011). However, Magness et al. 2011 is mistaken on its criteria; it does not list the Refuge as providing habitat for threatened or endangered species. As previously mentioned, the Refuge was established for the preservation of critical habitat for the federally listed endangered species, the Ozark Cavefish (USFWS 2015). When this criterion is taken into account the Magness et al. 2011 model yields a moderately vulnerable result. This means that OCNWR is the most vulnerable to climate change of the three refuges managed by Mingo NWR after updating the Magness et al. (2011) model.

Long-term projections

The nation as a whole has experienced a 1.3-1.9 degree Fahrenheit increase in average temperatures since 1895, and can expect a 2-4 degree increase over the next century (Melilo et al. 2014), although this change is not uniform over all regions of the country or over time (Winkler et al. 2012, Melilo et al. 2014). A 2004 study showed that areas in the central United States (including Missouri) are experiencing a local minimum of warming compared to the rest of the nation, due to the interaction between increased precipitation, soil moisture, and evapotranspiration (Pan et al. 2004). This results in reduced warming from July-October, and similar or increased warming during the cold-season (Pan et al. 2004). The southwest Midwest can expect an increase in average cold season temperatures by as much as 6 degrees Fahrenheit in the next century (Winkler et al. 2012), and the Midwest has experienced an increase from historic times in the average frost free season by 9 days (Melilo et al. 2014). Despite the past slower rate of warming than the rest of the nation, in the future Missouri can expect an increase in the number of >100 degree days per year from 3 (currently) to as many as 43 by 2070 under a high-emission scenario (UCS 2009).

Several reports indicate that the Midwest in general has already been affected by climate change. For example, heavy precipitation events are currently much more frequent and intense in the region than they were a century ago (Kunkel et al. 2003, Kunkel et al. 2013), and the Midwest has experienced an increase in runoff, with expectations of more intense flood conditions in the future (Johnson et al. 2013).

There are a number of models and studies that have evaluated current and anticipated trends in the Midwest, which provide supplementary information and a more comprehensive analysis of large-scale climatic conditions (e.g. Kunkel et al. 2003, Kunkel et al. 2013, UCS 2009, Groisman et al. 2005). Temperature projections for this region of the country are somewhat mixed. Most show general warming trends across the entire Midwest with the greatest increases possibly occurring northwest of Missouri (Kunkel et al. 2003). One model predicts an increase in average summer temperatures of 7-16 degrees by the end of the century (UCS 2009), however a NWRS climate change study (Magness et al. 2011) did not estimate any future rise in temperature based on historic rates of change from 1950-2006. Missouri as a whole is expected to experience drier summers and more frequent heavy precipitation events. In addition, over the next few decades winters and springs are expected to be approximately 20% wetter (UCS 2009). For all major watersheds that the Refuges occupy (Lower Missouri, Arkansas/White/Red, Lower Mississippi), the annual discharge has shown an increasing trend (Lins and Slack 2005).

PRISM and USHCN Datasets

Weather information was obtained from the PRISM Climate Group at Oregon State University (<http://prism.oregonstate.edu/>). The PRISM interpolation method provides spatial climate information for the conterminous United States, partially based on data from approximately 13,000 precipitation and 10,000 temperature stations. The dataset for temperature and precipitation is interpolated from nearby weather stations and corrected for elevation enabling point estimation.

Mingo National Wildlife Refuge

PRISM data was collected for Mingo NWR (36.9854, -90.1619) for comparison to data obtained from a site from the U.S. Historical Climatology Network ([USHCN]; <http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html>; Menne et al. 2012). The USHCN is a network of sites listed by the National Weather Service, which maintains standards in quality and continuity of data collection.

The closest USHCN station with adequate climate data is Poplar Bluff, MO No. 236791. It is located roughly 15 miles southwest of Mingo NWR. It has an elevation of 400 feet while Mingo NWR has an elevation of around 350 feet. Mean monthly temperature and precipitation data from the Poplar Bluff, MO site exhibit similar values and peaks to those modeled in the PRISM interpolation. Similarly, the annual total precipitation, as well maximum, average, and minimum temperatures are similar for both the PRISM and USHCN data. The years of 1903-1914, 1920, 1921, and 1983 were dropped from the analysis due to missing monthly data that led to erroneous annual statistics.

- The Poplar Bluff, MO USHCN weather station (1895-2015) showed a mean annual water year precipitation of 45.6 inches, with the wettest years on record occurring in 1927, 1973, 1950, 2011, 1929, and 1945, while particularly dry years occurred in 1980, 1984, 1922, 1953, 1992, and 1925 (Figure 10.1). The highest total monthly rainfall typically occurs March through July and the lowest in the Fall (Figure 3.15). Rainfall totals usually range between 3-5 inches per month from March until October.
- There is evidence of an increase in magnitude of extreme precipitation events since the beginning of the data record (1893) (Figure 3.18) This shows that there has been an increase over time in the number of days in a year with greater than two inches of precipitation (median = 3.0, $p = 0.008$, $r^2 = 0.06$).
- The trend for increased extreme precipitation is further explored in Table 3.2. Rainfalls of 0.5 inches or greater in a day have increased in the past 30 years compared to the historic record, while rainfalls 0.25 to 0.5 inches have shown a decrease. Overall days with rainfall (> 0.01 "") have shown an increase as well.
- Average cool season precipitation (October to March) has shown a statistically significant increase over time ($p < 0.001$) (Figure 10.2).
- Average monthly temperatures are typically highest in July and coolest in January (Figure 3.16). Average annual mean temperatures have not changed from historic norms, however both the annual average maximum and minimum temperatures have. The annual average maximum temperatures have shown a statistically significant decrease over time ($p < 0.001$, median = 69.57), while the annual average minimum temperatures have shown significant increases over time ($p < 0.001$, median = 46.67) (Figure 10.3).
- Average growing length season has shown a statistically significant increase over the period of record (1893-2015) (median = 202, $p < 0.001$, $r^2=0.334$) (Figure 3.17). Table 3.3 shows

that while the occurrence of extreme heat days has decreased in the past 30 years compared to the present, the average number of days with a high of less than 40 degrees F have decreased.

- Climate teleconnections displayed statistically significant relationships between the Pacific Decadal Oscillation (PDO) and both the annual daily average ($p = 0.043$) and average annual daily maximum temperature ($p = 0.026$) (Figure 10.5, 10.6).
- Decadal climate variability associated with changes in other climate anomaly indices. Particularly PDO effects can serve to modulate the El Niño Southern Oscillation in general (Kurtzman et al. 2007). Southern Missouri is located in a wet El Niño winter region of the United States, but it is not typically a region with high correlation between precipitation anomalies and ENSO. It is more often associated with effects from PDO phases, especially during La Niña, with precipitation being up to 19% lower than average during a strong La Niña event (Kurtzman et al. 2007). There is also a strong correlation between Cool-Phase PDO/La Niña and drought probability index in the area (Kam et al. 2014). While the analysis of the Poplar Bluff USHCN station did not find a statistical relation between the two, it did show that the precipitation had a much stronger relationship with PDO with a Chi-Squared of 3.65, as opposed to either SOI (1.01) or PNA (1.38).

Kendall's Tau Non-Parametric Monotonic Trend Test

Dependent Variable	p-value	slope	median
<i>Annual Average Maximum Temp</i>	< 0.001	(-)	69.57
<i>Annual Average Minimum Temp</i>	< 0.001	(+)	46.67
<i>Cool Season Average Maximum Temp</i>	< 0.001	(-)	73.83
<i>Cool Season Average Minimum Temp</i>	< 0.001	(+)	50.75
<i>Annual # Days With Precipitation > 2"</i>	0.008	(+)	3.0
<i>Cool Season Average Precipitation</i>	0.029	(+)	20.28

Kruskal-Wallis One-Way ANOVA

Relationship	Chi-Squared	p-value
<i>Pacific Decadal Oscillation and Average Max Temp</i>	7.337	0.026
<i>Pacific Decadal Oscillation and Average Temp</i>	6.291	0.043

Table 3.1: Statistically significant climate trends for 1895-2015, Station No. 236791, Poplar Bluff, MO

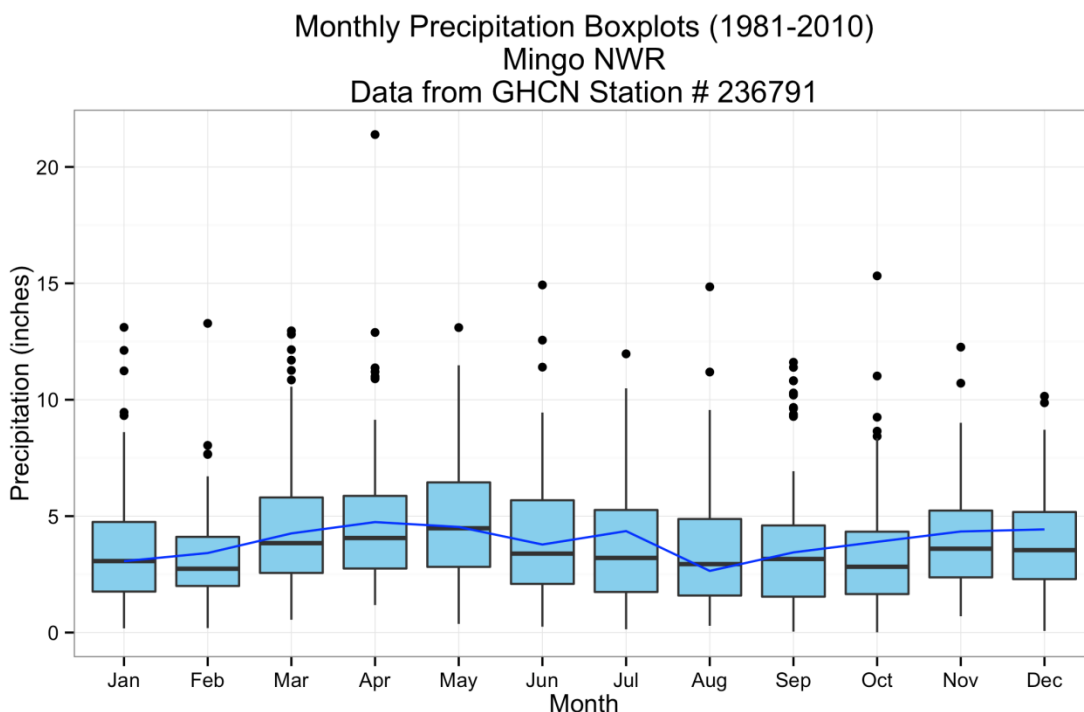


Figure 3.15: Average total monthly precipitation (1981-2010), Station No. 236791, Poplar Bluff, MO

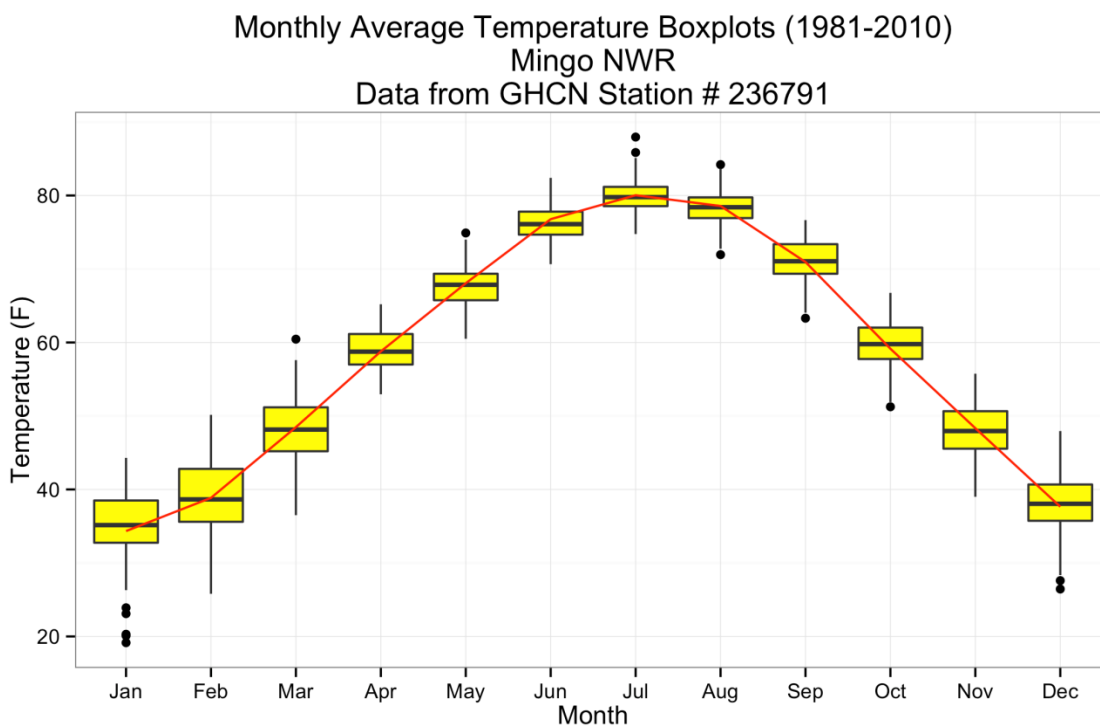


Figure 3.16: Average monthly temperatures (1981-2010), Station No. 236791, Poplar Bluff, MO

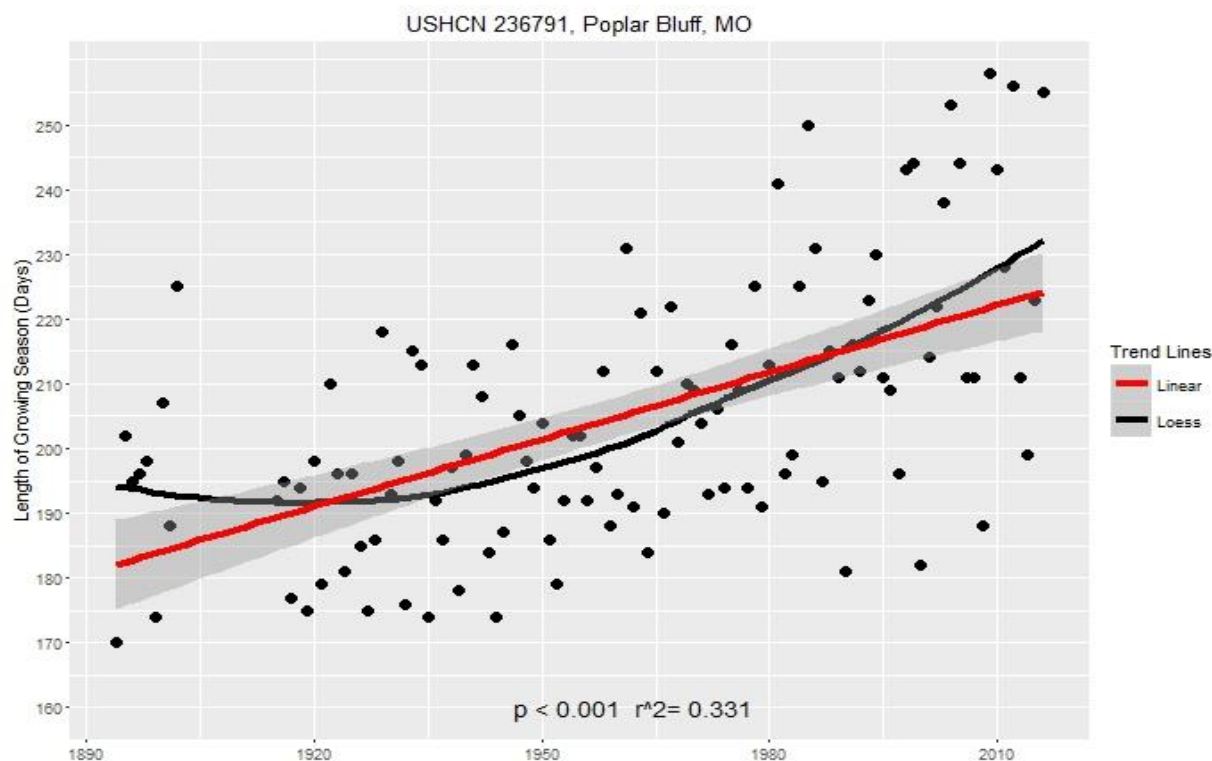


Figure 3.17: Length of growing season (last freeze in Spring to first freeze in Fall) for Poplar Bluff, MO 1893-2015. Red line is a fitted linear regression, black line is a Loess regression (span = 0.5)

Inches of rain in a day equaled or exceeded	Avg. Number of days/year (1895-1984)	Avg. Number of days/year (1985-2015)	Percent Change
5.00	0.101	0.179	+ 76%
4.00	0.159	0.464	+ 191%
3.00	0.797	1.214	+ 52%
2.00	2.711	3.839	+ 45%
1.00	12.90	14.57	+ 12%
0.50	30.14	31.54	+ 4.6%
0.25	48.62	47.93	- 1.4%
0.10	66.91	64.32	- 3.9%
0.05	76.87	75.64	- 1.6%
0.01	89.43	95.36	+ 5.5%

Table 3.2: Cumulative frequency of daily rain for Poplar Bluff, MO.

Maximum temperature in a day equaled or exceeded	Avg. Number of days/year (1895-1984)	Avg. Number of days/year (1985-2015)	Percent Change
100	4.261	2.250	- 47%
90	52.46	48.64	- 7.6%
80	131.7	127.3	- 3.3%

70	191.9	186.3	- 2.9%
60	243.8	238.9	- 2.0%
50	289.5	288.0	- 0.5%
40	326.8	329.1	+ 0.7%
30	347.2	351.8	+ 1.3%
20	352.3	358.4	+ 1.7%

Table 3.3: Cumulative frequency of daily maximum temperature (F) for Poplar Bluff, MO
USHCN 236791, Poplar Bluff, MO

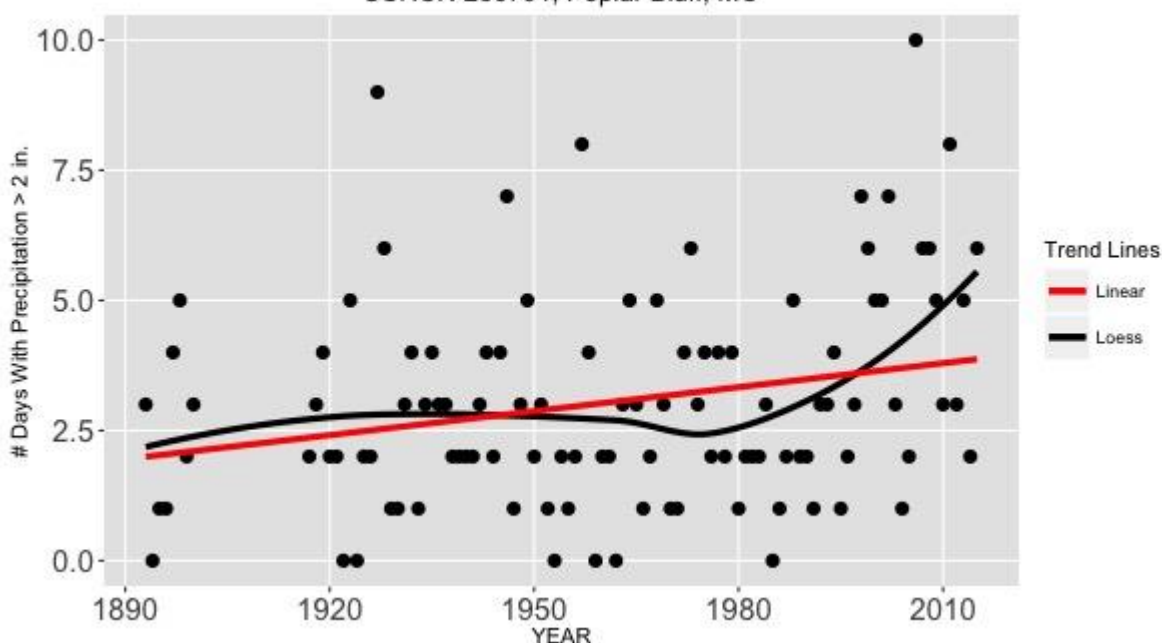


Figure 3.18: Average number of extreme precipitation events (> 2 inches in a day) for Poplar Bluff, MO (1893-2015).

Pilot Knob National Wildlife Refuge

PRISM data was collected for Pilot Knob NWR (37.6161, -90.6234) for comparison to data obtained from a site from the U.S. Historical Climatology Network (USHCN). The closest USHCN station with adequate climate data is Farmington, MO No. 232809. It is located roughly 12 miles northeast of Pilot Knob NWR. It has an elevation of 910 feet while PKNWR has an elevation of around 1,129 feet. Mean monthly temperature and precipitation data from the Farmington, MO site exhibit similar values and peaks to those modeled in the PRISM interpolation. Similarly, the annual total precipitation, as well maximum, average, and minimum temperatures follow each other quite closely for both the PRISM and USHCN data. The years of 1906-1910, 1933, 1946, 1967, 1968, and 1984 were dropped from the analysis due to missing monthly data which led to erroneous annual statistics.

- The Farmington, MO USHCN weather station (1919-2015) showed a mean annual water year precipitation of 41.2 inches, with the wettest years on record occurring in 1985, 1945, 1958, 2015, 1993, and 1957, while particularly dry years occurred in 1936, 1919, 1940, 1930, 1934, and 1976 (Figure 10.7). The highest total monthly rainfall typically occurs March through May and the lowest in December and January (Figure 3.19). Rainfall totals usually range between 2-5 inches per month from March through October.

- There are no statistically significant trends regarding annual or seasonal precipitation over time (Figure 10.1). However, Table 3.5 shows that number of days of precipitation is greater for the past 30 years compared to the historical record.
- Average monthly temperatures are typically highest in July and coolest in January (Figure 3.20). Average annual mean temperatures have shown decreases over the period of record ($p = 0.001$, median = 55.43).
- Climate teleconnections displayed statistically significant relationships between the Pacific Decadal Oscillation (PDO) and both the annual daily average ($p = 0.002$) and average annual daily maximum temperature ($p < 0.001$) (Figure 10.10, 10.11). There is also a significant relationship between the Pacific/North American Pattern and average annual daily maximum temperature ($p = 0.035$) (Figure 10.12).

Kendall's Tau Non-Parametric Monotonic Trend Test

Dependent Variable	p-value	slope	median
<i>Annual Average Maximum Temp</i>	< 0.001	(-)	66.86
<i>Annual Average Temp</i>	0.001	(-)	55.43
<i>Average Cool Season Temp</i>	0.009	(-)	41.50

Kruskal-Wallis One-Way ANOVA

Relationship	Chi-Squared	p-value
<i>Pacific Decadal Oscillation and Max Temp</i>	22.49	< 0.001
<i>Pacific Decadal Oscillation and Ave Temp</i>	12.08	0.002
<i>Pacific/ North American Pattern and Max Temp</i>	6.73	0.035

Table 3.4: Statistically significant climate trends for 1919-2015, Station No. 232809, Farmington, MO

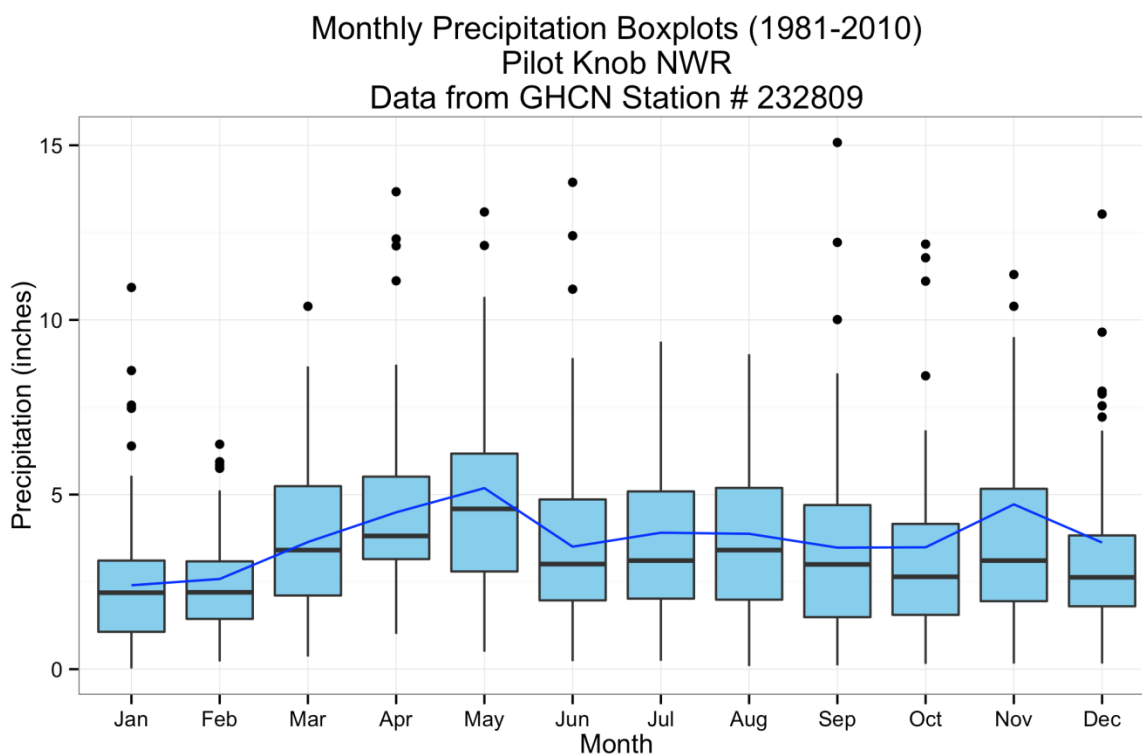


Figure 3.19 Average total monthly precipitation (1981-2010), Station No. 232809, Farmington, MO

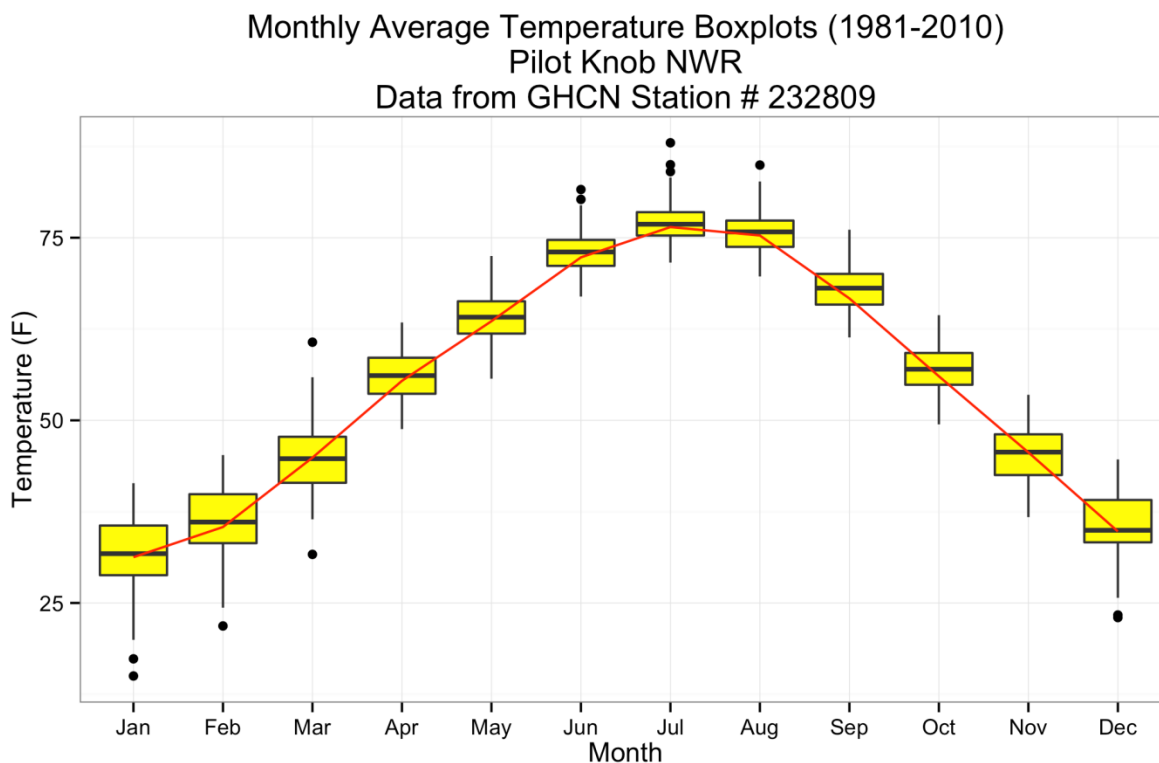


Figure 3.20: Average monthly temperatures (1981-2010), Station No. 232809, Farmington, MO

Inches of rain in a day equaled or exceeded	Avg. Number of days/year (1895-1984)	Avg. Number of days/year (1985-2015)	Percent Change
5.00	0.032	0	NA
4.00	0.082	0.111	+ 36%
3.00	0.393	0.333	- 15%
2.00	2.295	2.370	+ 3.2%
1.00	10.28	12.26	+ 19%
0.50	26.98	29.48	+ 9.3%
0.25	46.39	48.74	+ 5.1%
0.10	67.18	69.48	+ 3.4%
0.05	78.93	82.00	+ 3.9%
0.01	95.84	102.7	+ 7.1%

Table 3.5: Cumulative frequency of daily rain for Farmington, MO.

Ozark Cavefish National Wildlife Refuge

PRISM data was collected for Ozark Cavefish NWR- Turnback Cave Unit (37.1987, -93.6945) for comparison to data obtained from a site from the U.S. Historical Climatology Network. The closest USHCN station with adequate climate data is Mt. Vernon, MO No.

235862. It is located roughly 13.5 miles northeast of Turnback Cave. It has an elevation of 1,200 feet while Turnback Cave has an elevation of around 1,100 feet. Mean monthly temperature and precipitation data from the Mt. Vernon, MO site exhibit similar values and peaks to those modeled in the PRISM interpolation. Similarly, the annual total precipitation, as well as maximum, average, and minimum temperatures follow each other quite closely for both the PRISM and USHCN data. However, only the years of 1961-2012 had complete records of data.

- The Mt. Vernon, MO USHCN weather station (1961-2012) showed a mean annual water year precipitation of 43.5 inches, with the wettest years on record occurring in 1993, 2008, 1985, 1973, 2007, and 1974, while particularly dry years occurred in 1980, 1963, 1987, 1967, 1964, and 1961 (Figure 10.13). The highest total monthly rainfall typically occurs March through June and the lowest in January and February (Figure 3.21). Rainfall totals usually range between 4-6 inches per month from March through October.
- The average number of days per year with precipitation totals greater than or equal to 0.1 inches, 0.5 inches, and 1 inch are 64.6, 27.9, and 12.3 days, respectively (1961-2012).
- The average amount of cool season precipitation (October to March) has shown a statistically significant positive trend over time ($p = 0.047$) (Figure 10.14).
- Average monthly temperatures are typically highest July to August and coolest January to December (Figure 3.22). Average annual mean and maximum temperatures have shown increases over the period of record ($p = 0.045$, median = 55.75; $p = 0.020$, median = 66.8, respectively) (Figure 10.15).
- Climate teleconnections displayed statistically significant relationships between the Pacific Decadal Oscillation (PDO) and both the annual daily average ($p = 0.008$) and average annual daily maximum temperature ($p = 0.002$) (Figure 10.16).

Kendall's Tau Non-Parametric Monotonic Trend Test

Dependent Variable	p-value	slope	median
<i>Average Annual Maximum Temp</i>	0.020	(+)	66.84
<i>Average Annual Temp</i>	0.045	(+)	55.75
<i>Average Cool Season Precipitation</i>	0.047	(+)	16.11

Kruskal-Wallis One-Way ANOVA

Relationship	Chi-Squared	p-value
<i>Pacific Decadal Oscillation and Max Temp</i>	12.61	0.002
<i>Pacific Decadal Oscillation and Ave Temp</i>	9.65	0.008

Table 3.6: Statistically significant climate trends for 1961-2012, Station No. 235862, Farmington, MO

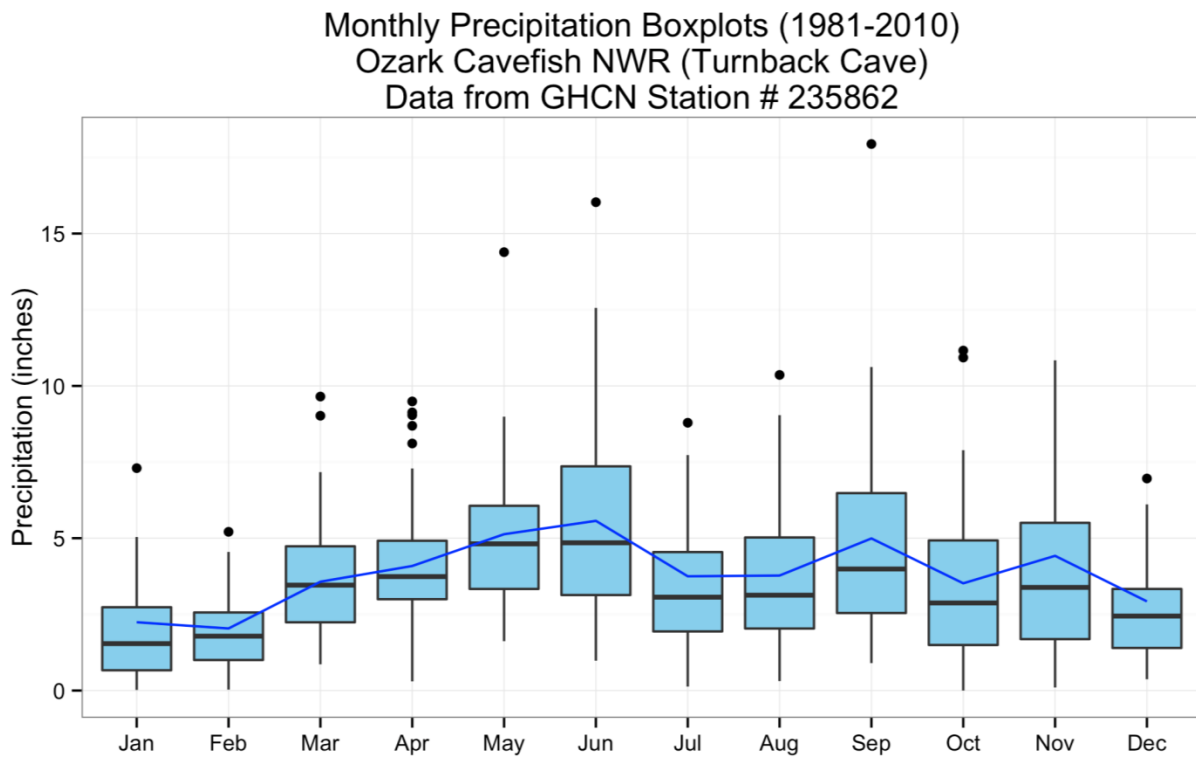


Figure 3.21: Average total monthly precipitation (1981-2010), Station No. 235862, Mt. Vernon, MO

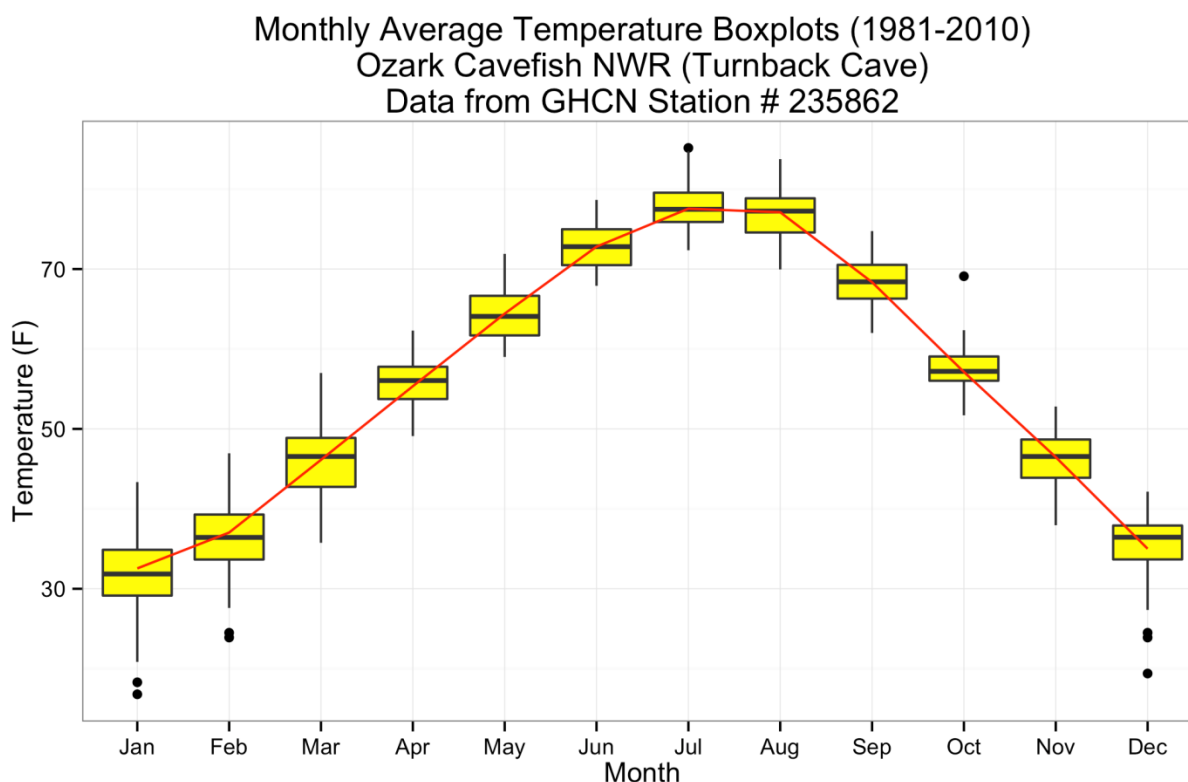


Figure 3.22: Average monthly temperatures (1981-2010), Station No. 235862, Mt. Vernon, MO

PRISM data was collected for Ozark Cavefish NWR- Hearrell Spring Unit (36.8591, -94.3587) for comparison to data obtained from a site from the U.S. Historical Climatology Network ([USHCN]; <http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html>; Menne et al. 2012). The USHCN is a network of sites listed by the National Weather Service, which maintains standards in quality and continuity of data collection.

The closest USHCN station with adequate climate data is Neosho, MO No. 235976. It is located less than 1,000 feet north of Hearrell Spring and shares roughly the same elevation. Mean monthly temperature and precipitation data from the Neosho, MO site exhibit similar values and peaks to those modeled in the PRISM interpolation. Similarly, the annual total precipitation, as well as maximum, mean, and minimum temperatures follow each other quite closely for both the PRISM and USHCN data. The year 1895 was excluded from the analysis due to incomplete records.

- The Neosho, MO USHCN weather station (1896-2015) showed a mean annual precipitation (for the water year) of 44.6 inches, with the wettest years on record occurring in 1993, 2008, 1945, 1973, 1942, and 1927, while particularly dry years occurred in 1963, 1956, 1934, 1954, 1953, and 1980 (Figure 10.17). The highest total monthly rainfall typically occurs March through June and the lowest in December through February (Figure 3.23). Rainfall totals usually range between 4-6 inches per month from March until October.

- Table 3.8 shows the increase in daily precipitation 0.10 inches and greater in the past 30 years compared to the historical record. Daily precipitation 0.10 inches or less has decreased.
- Average monthly temperatures are typically highest in July to August and coolest in January to December (Figure 3.24). Average annual mean and maximum temperatures have shown decreases over the period of record ($p = 0.030$, median = 57.45; $p < 0.001$, median = 69.8, respectively). Table 3.9 shows the decrease in the occurrence of maximum temperatures in the past 30 years compared to the historical record.
- Climate teleconnections displayed statistically significant relationships between the Pacific Decadal Oscillation (PDO) and both the annual daily average ($p = 0.008$) and average annual daily maximum temperature ($p < 0.001$), as well as annual average precipitation ($p = 0.045$). There were also significant relationships between both the Pacific/North American Pattern and Southern Oscillation Index and the annual average maximum temperature ($p = 0.026$, $p = 0.037$, respectively) (Figures 10.19-10.21).

Kendall's Tau Non-Parametric Monotonic Trend Test

Dependent Variable	p-value	slope	median
<i>Annual Average Maximum Temp</i>	< 0.001	(-)	69.80
<i>Cool Season Average Maximum Temp</i>	0.001	(-)	56.62
<i>Cool Season Average Temp</i>	0.008	(-)	44.47
<i>Annual Average Temp</i>	0.033	(-)	57.45

Kruskal-Wallis One-Way ANOVA

Relationship	Chi-Squared	p-value
<i>Pacific Decadal Oscillation and Max Temp</i>	7.613	0.022
<i>Pacific/North American Pattern and Max Temp</i>	7.310	0.026
<i>Southern Oscillation Index and Max Temp</i>	6.594	0.037
<i>Pacific Decadal Oscillation and Ave Temp</i>	6.332	0.042
<i>Pacific Decadal Oscillation and Ave Precip</i>	6.215	0.045

Table 3.7: Statistically significant climate trends for 1919-2015, Station No. 235976, Neosho, MO

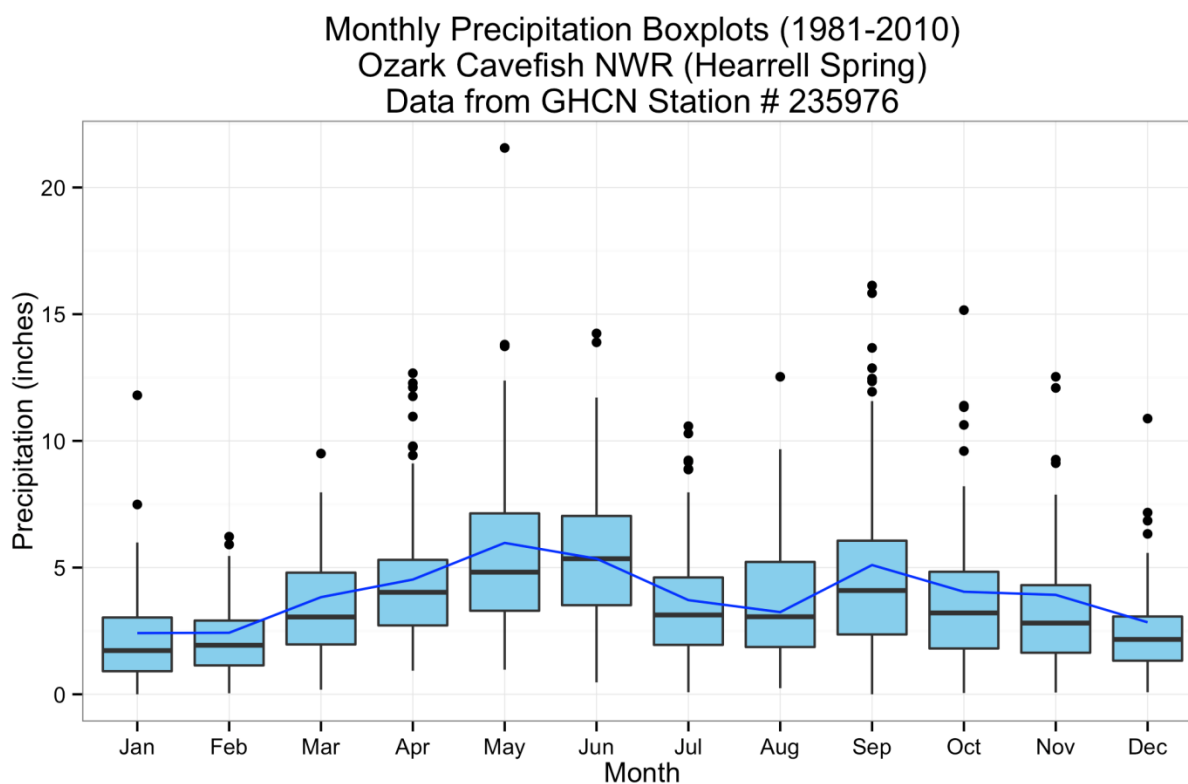


Figure 3.23: Average total monthly precipitation (1981-2010), Station No. 235976, Neosho, MO

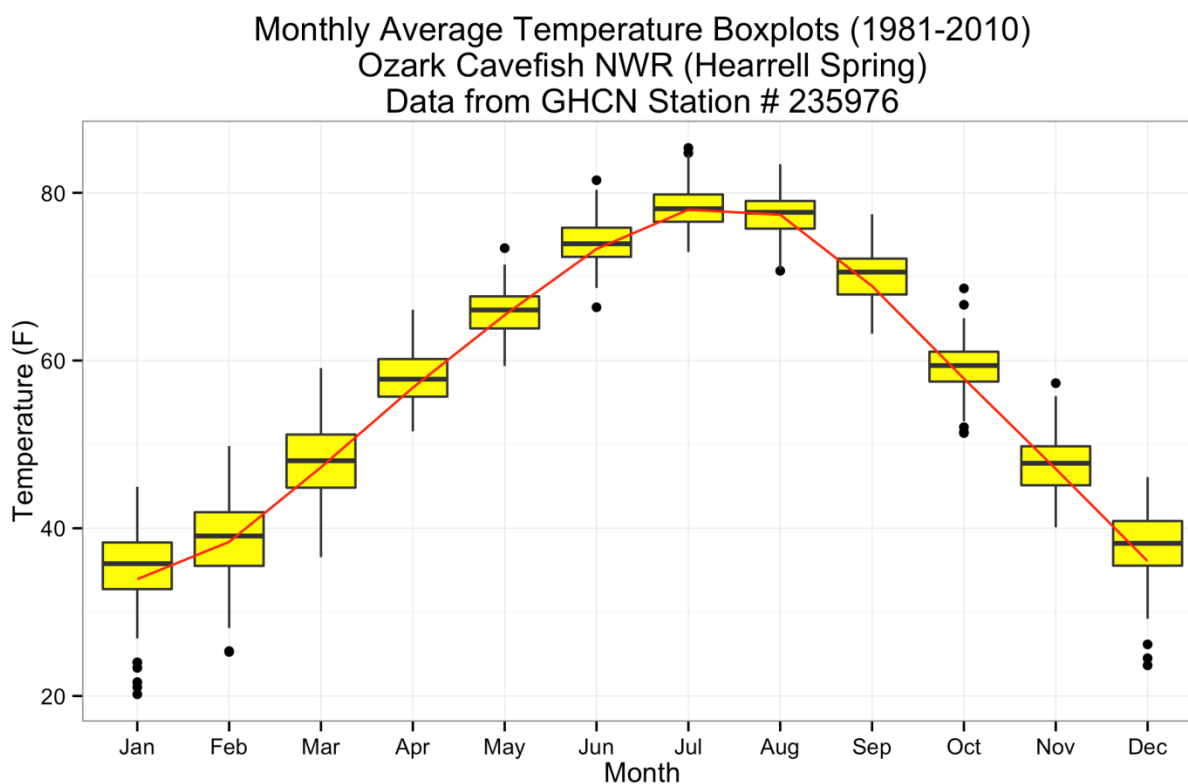


Figure 3.24: Average monthly temperatures (1981-2010), Station No. 235976, Neosho, MO

Inches of rain in a day equaled or exceeded	Avg. Number of days/year (1893-1984)	Avg. Number of days/year (1985-2015)	Percent Change
5.00	0.087	0.194	+ 122%
4.00	0.272	0.484	+ 78%
3.00	0.761	1.194	+ 56%
2.00	2.772	3.935	+ 42%
1.00	12.37	14.29	+ 16%
0.50	28.78	31.06	+ 7.9%
0.25	45.65	46.77	+ 2.5%
0.10	63.57	64.26	+ 1.1%
0.05	74.45	74.06	- 0.5%
0.01	90.43	84.35	- 6.7%

Table 3.8: Cumulative frequency of daily rain for Poplar Bluff, MO.

Maximum temperature in a day equaled or exceeded	Avg. Number of days/year (1895-1984)	Avg. Number of days/year (1985-2015)	Percent Change
100	2.761	1.323	- 52%
90	45.85	34.23	- 25%
80	131.9	113.9	- 14%
70	197.7	184.5	- 6.7%

60	252.8	243.6	- 3.6%
50	301.0	290.2	- 3.6%
40	334.8	326.6	- 2.4%
30	354.3	350.0	- 1.2%
20	361.9	359.8	- 0.7%

Figure 3.9: Cumulative frequency of daily maximum temperature (F) for Poplar Bluff, MO

Hydroclimatic Data Network

Reference hydrographs obtained from the Hydro-Climatic Data Network (HCDN) provide additional context for the assessment of surface water quantity patterns (see surface water quantity discussion in water monitoring section). The HCDN is a network of USGS stream gages located within relatively undisturbed watersheds, which are appropriate for evaluating trends in hydrology and climate that are affecting flow conditions (Slack et al., 1992). This network attempts to provide a look at hydrologic conditions without the confounding factors of direct water manipulation and land use changes. Annual peak discharge and average annual discharge trends were compared for this analysis. The nearest HCDN sites were chosen to represent each of the refuges described in this document. For Mingo NWR and Pilot Knob NWR, this was the Current River at Van Buren, MO ([USGS-07067000](#)), for OCNWR-Turnback Cave, it was Turnback Creek near Greenfield, MO ([USGS- 06918460](#)), and for OCNWR-Hearrell Spring, it was Flint Creek at Springtown, AR ([USGS-07195800](#)).

The Current River at Van Buren, MO was the chosen HCDN site for Mingo NWR and Pilot Knob NWR. While not located in the same watershed as either refuge, it was chosen due to its proximity, its similar latitude, and similar drainage basin land cover types compared to the two refuges. It is the closest HCDN site, it lies just west of the two Refuges, and it drains the Ozark Plateau, similar to the St. Francis River and Mingo Basin. The dataset from this site includes streamflow data recorded from 1963-present, however there is a gap in the data from 1991-2001. It is apparent from observing the time series average annual discharge and annual peak discharge, that there has been an increase in both peak and average annual discharge over the past 53 years (Figure 3.25). Simple linear regression of the average annual and peak discharge for each year indicates that neither of these relationships are statistically significant. The average annual discharge showed a stronger trend than that of the peak annual discharge with a p value of 0.11. This seems to show that annual discharge is showing an increase over time but this increase is not strong enough to be considered statistically significant.

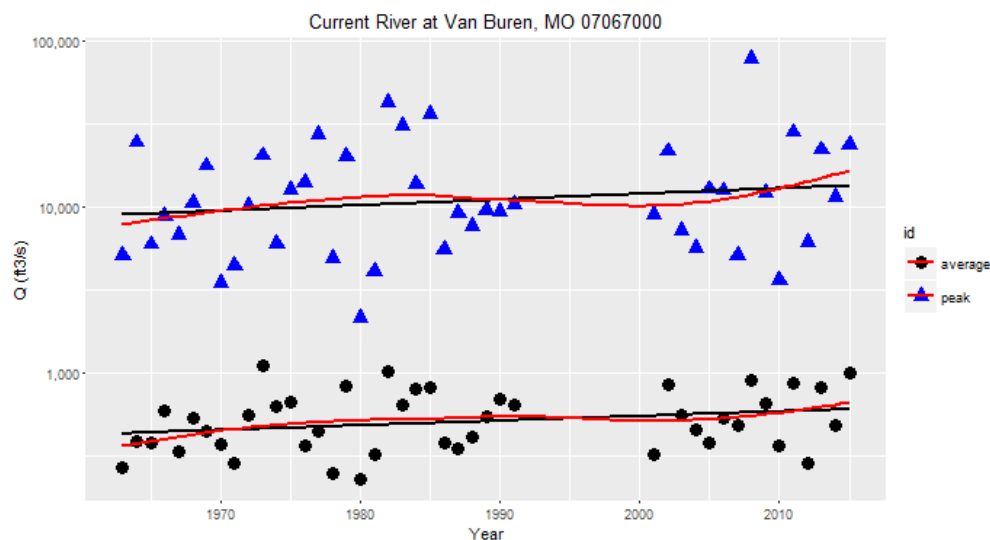


Figure 3.25: Average annual discharge data for Current River at Van Buren, MO (1963-2016) (USGS-07067000). Black line is a fitted linear regression, red line is a Loess regression.

For the Ozark Cavefish NWR-Turnback Cave site, the Turnback Creek gage near Greenfield, MO was used. This was the closest gage to the refuge that was within the same watershed (approximately 14.5 miles). The dataset from this site includes streamflow data recorded from 1965-present. It is apparent from observing the time series average annual discharge and annual peak discharge, that there has been a small increase both in average discharge and peak discharge over the past 50 years (Figure 3.26, 3.27). Simple linear regression of the average annual and average peak discharge for each year indicates that neither of these relationships are statistically significant, also the trend for average annual discharge is much weaker than that of annual peak discharge ($p = 0.63$, $p = 0.11$). The annual discharge in the area around Ozark Cavefish NWR has not changed considerably in the 1965-2015 time period.

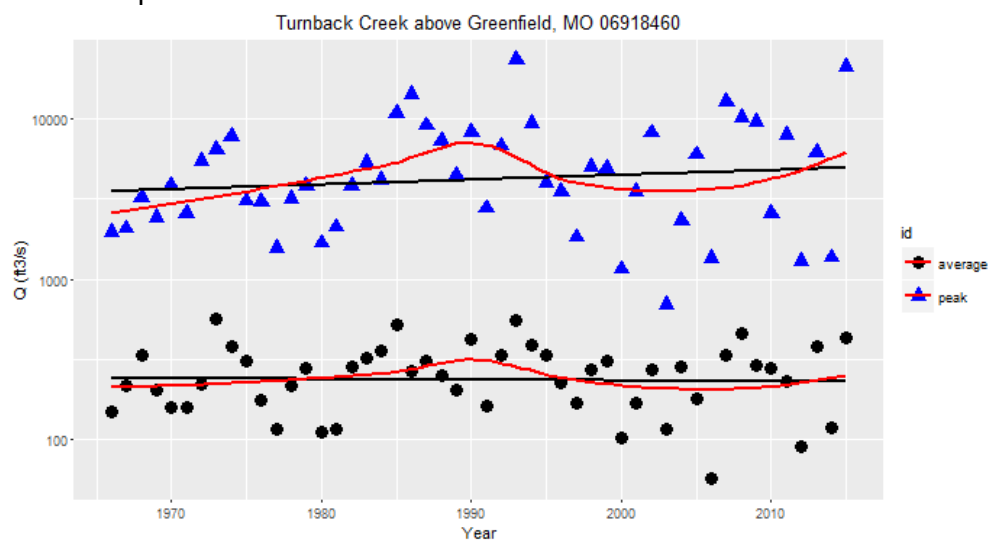


Figure 3.26: Average annual discharge data for Turnback Creek near Greenfield, MO (1965-2015) (USGS-06918460). Black line is a fitted linear regression, red line is a Loess regression.

For the Ozark Cavefish NWR-Hearrell Spring site, the Flint Creek gage at Springtown, AR was used. This was the closest gage to the refuge that shared a similar drainage area and land cover. The dataset from this site includes streamflow data recorded from 1961-present. It is apparent from observing the time series average annual and peak discharge has increased slightly over time (Figure 3.27). However linear regression of the average annual discharge and peak discharge for each year shows that there is no statistically significant trend for either parameter ($p = 0.66$, $p = 0.51$). The annual discharge in the area around Hearrell Spring has likely not changed considerably in the 1925-2015 time period.

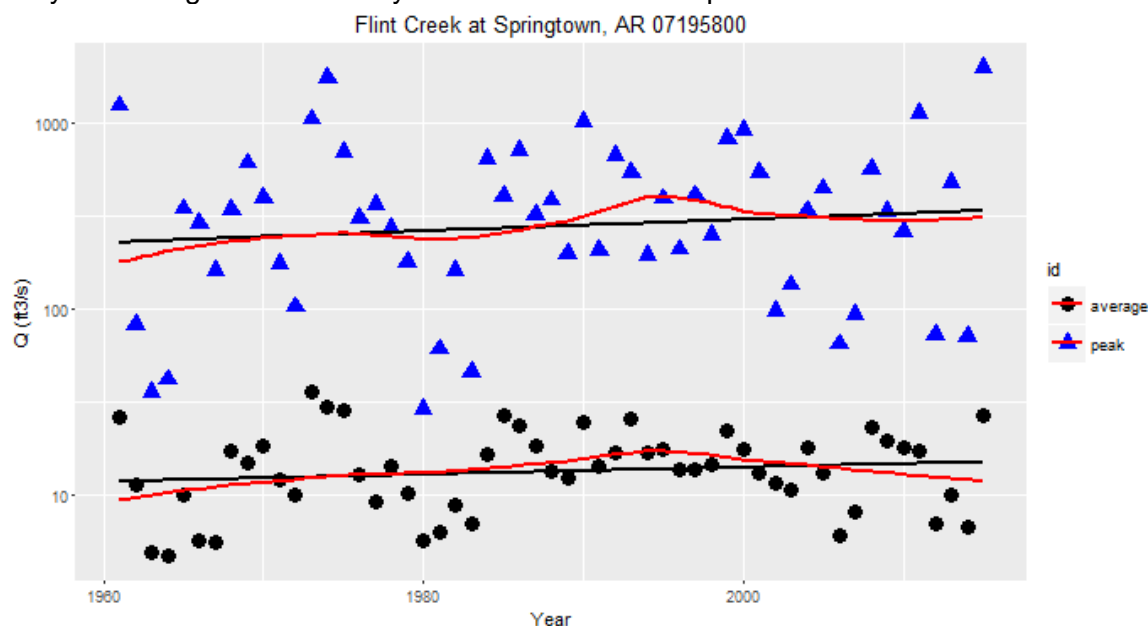


Figure 3.27: Average and peak annual discharge data for Flint Creek at Springtown, AR (1961-2016) (USGS-07195800). Black line is a fitted linear regression, red line is a Loess regression.

4. Water Resource Features

4.1 Management Units

Extensive information related to the Refuge's management strategies is provided in the HMP (USFWS 2011). Mingo NWR is an actively managed property with an extensive system of dikes, levees, drainage ditches, impoundments, wetlands, farm units, and moist soil units (Figure 4.1). The Refuge attempts to mimic natural cycles with spring fall flooding and drawdowns between May and June. Management areas include 33 individual management units totalling over 10,160 acres, and 72 water control structures used to meet management targets. Structure elevations as of March 2012 and additional notes are listed in Table 11.3. No structures or active management occurs at OCNWR or PKNWR. Sedimentation is a big issue in the Refuge's ditch system. Refuge staff implemented a ditch-cleanout process in the late 1990s. Every year, MNWR attempts to eliminate silt, trees, debris, and obstructions from at least one mile of their primary ditch system (Refuge staff, personal communication, May 2016, FWS 2007).

The Refuge shares an eight -mile management boundary with Missouri Department of Conservation's (MDC) Duck Creek Conservation Area (CA), including Ditch #1 and Ditch #11 adjacent to MNWR's Pool 8 (Figure 4.2). Active communication between MNWR and MDC staff is imperative to water management activities through these ditches (Refuge staff, personal communication, 2016).

The Refuge also struggles in different ways with managing water, depending on the time of year (Refuge staff, personal communication, 2016). Flooding moist soil units and green tree impoundments is typically most challenging in early fall, when source water supply is inadequate to supply all the units. Other times of the year there is too much water, which is the combined effect of excessive precipitation and the limitations of MNWR's ditch system. The ditch system is prone to debris jams, siltation, sediment infilling, beaver dams, and fallen trees; all of which reduce conveyance and delay drainage during periods of flooding. Green tree impoundments are often flooded in the spring due to insufficient drainage in the Refuge, as the trees are active and budding, when conditions should ideally be dry, and this can caused mortality to the tress.. The Refuge's largest unit, Monopoly Marsh, is managed as a semi-permanent marsh, but high stages occur most years, resulting in tree die. A greater ability to draw down Monopoly marsh on a semi-annual basis would allow the Refuge to better achieve their habitat management goals (Refuge staff, personal communication, 2016).

One of the Refuge's greatest constraints is related to its main outlet water control structure and the 25-30 foot-wide channel draining into it (Figure 4.3, Item #34). This outlet drains water from roughly half of the Mingo basin, including 40,000 acres of flooded forested wetlands (Refuge staff, personal communication, 2016). Recently, construction has taken place to double this structure's capacity through partnership with Ducks Unlimited and North American Wetlands Conservation Act funding, which will greatly enhance the Refuge's management capabilities.

MNWR staff's ability to manage the Mingo Wilderness Area is very challenging because mechanical and motorized equipment in this area is prohibited. Over the past 40 years since its establishment, water management in this area has been limited to occasional ditch cleaning. An earthen plug on Ditch 10, water is impounded throughout much of the Wilderness area including the Stanley Creek and Mingo Creek areas. This has resulted in the die of hardwood forest

stands which is not the desired habitat condition for this area (Refuge staff, personal communication, 2016).

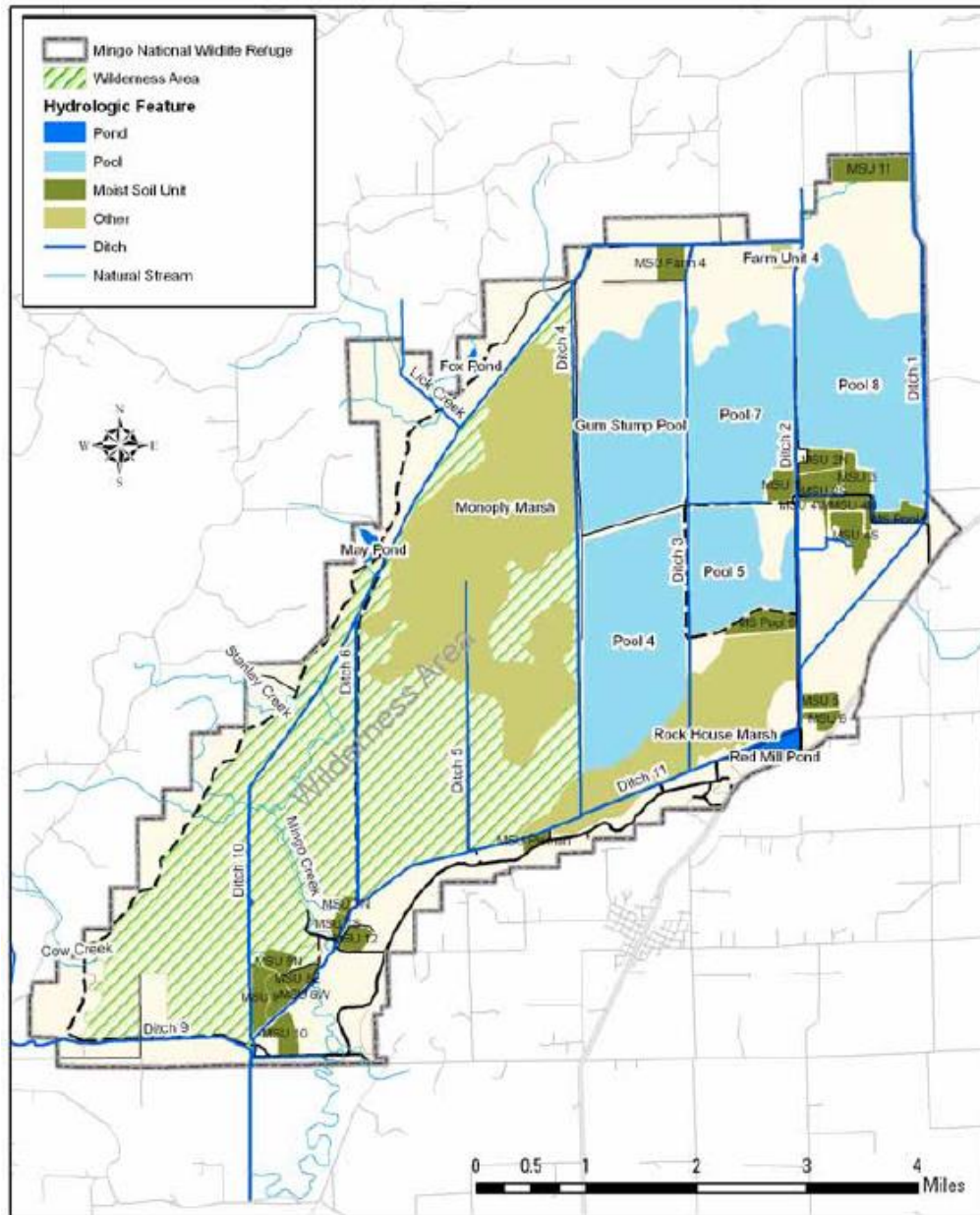
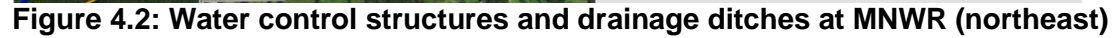


Figure 4.1: Management units at Mingo NWR (USFWS 2007)



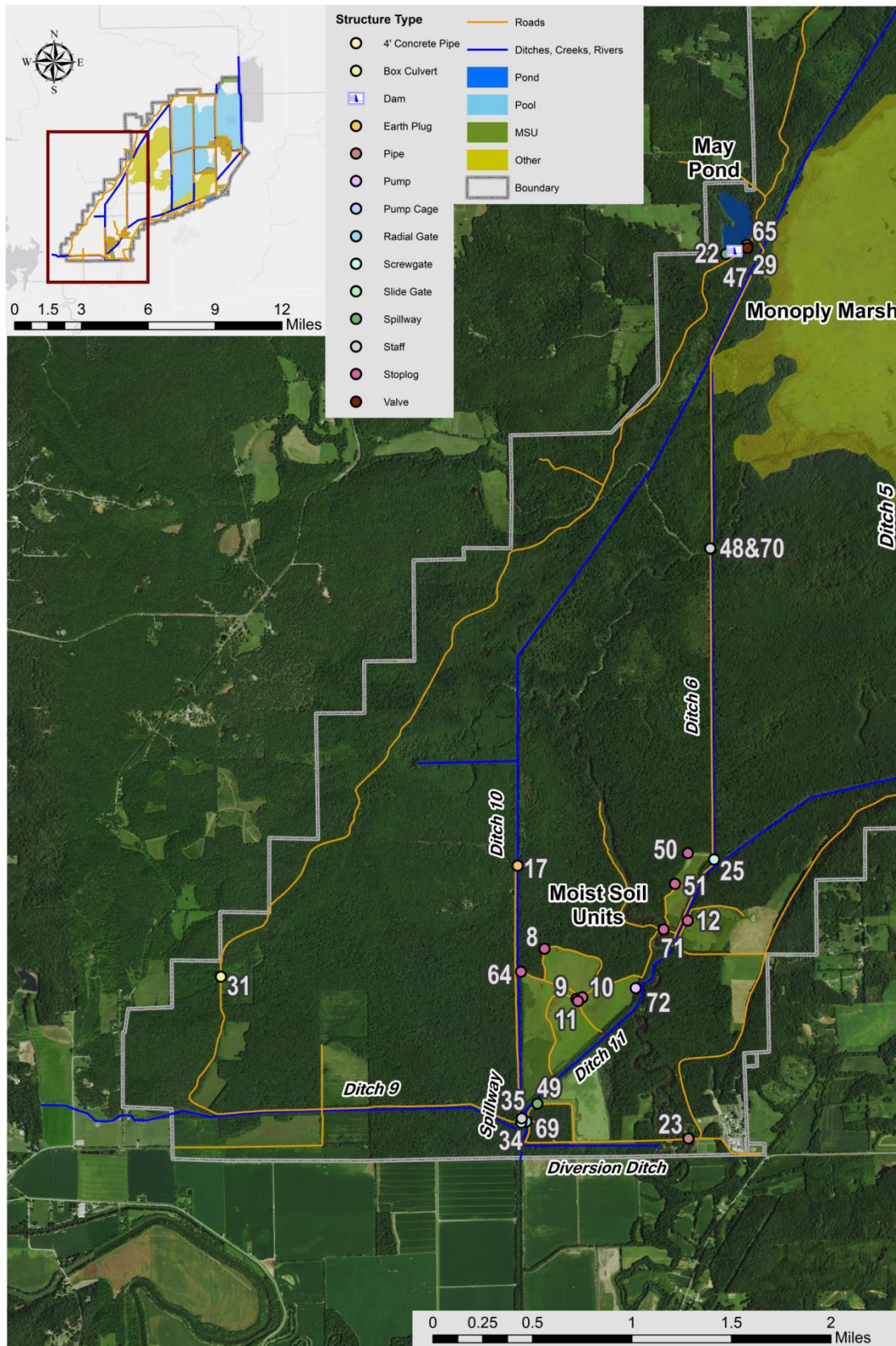


Figure 4.3: Water control structures and drainage ditches at MNWR (southwest)

4.2 National Wetlands Inventory

MNWR's wetland tracts can be described with the National Wetlands Inventory (NWI), which is an extensive, ongoing survey by the U.S. Fish and Wildlife Service of aquatic habitats across the United States. This is a national published dataset, however its accuracy is limited, especially with respect to the classifications and acreage values. The NWI has not necessarily been verified with ground truth surveys and may be limited by the quality of the imagery used to derive the dataset. For example, the NWI information collected for MNWR appears to overestimate total wetland acreage.

According to the NWI classification within MNWR's acquisition boundary, much of the mapped units are freshwater forested/shrub wetlands (Figure 4.4). No wetlands were classified within OCNWR and PKNWR, however three small freshwater pond units were identified within the fish hatchery boundary at NNFH (Figures 4.5-4.7).

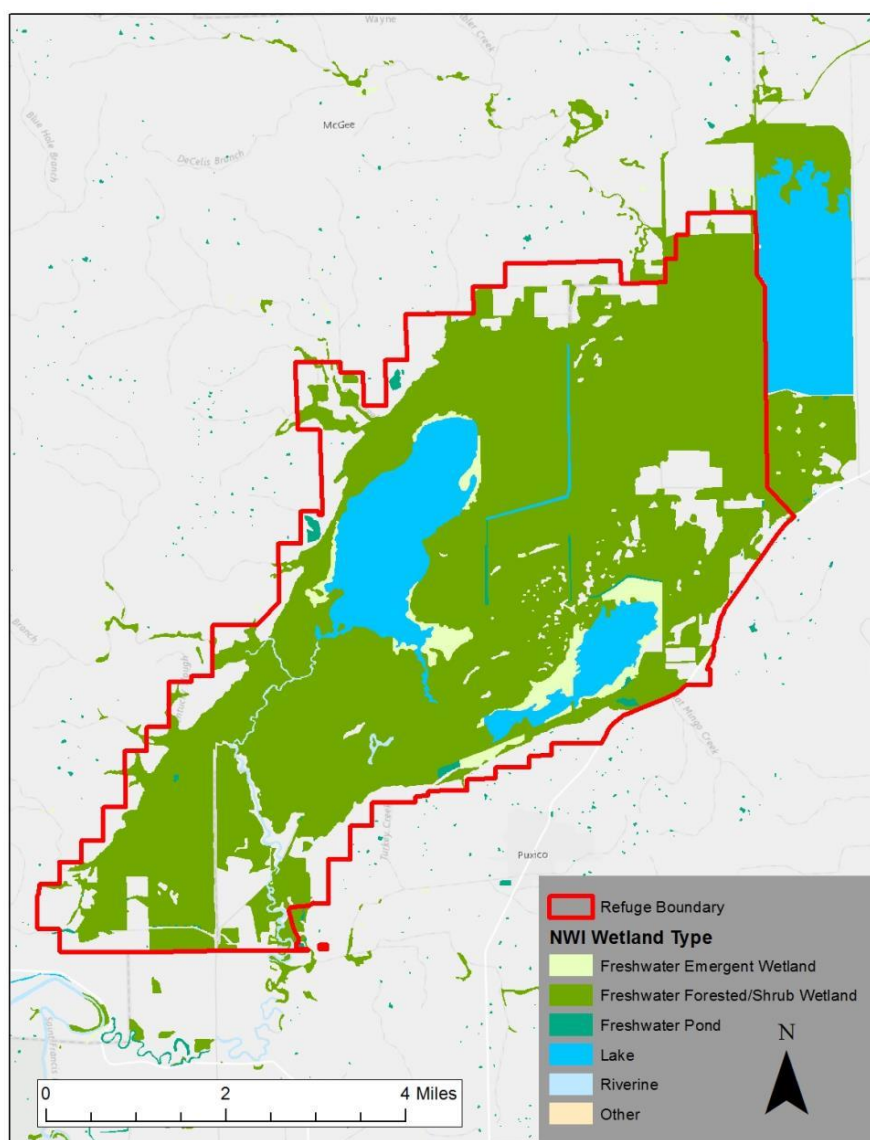


Figure 4.4: Wetland types found at MNWR

Wetland Type	Acres	Percent
Freshwater Emergent Wetland	611.42	3.47%
Freshwater Forested/Shrub Wetland	14714.72	83.51%
Freshwater Pond	120.65	0.68%
Lake	2060.97	11.70%
Riverine	113.44	0.64%
Total	17621.21	100.0%

Table 4.1: Wetland types and acreage at MWNR



Figure 4.5: Wetland types found near PKNWR

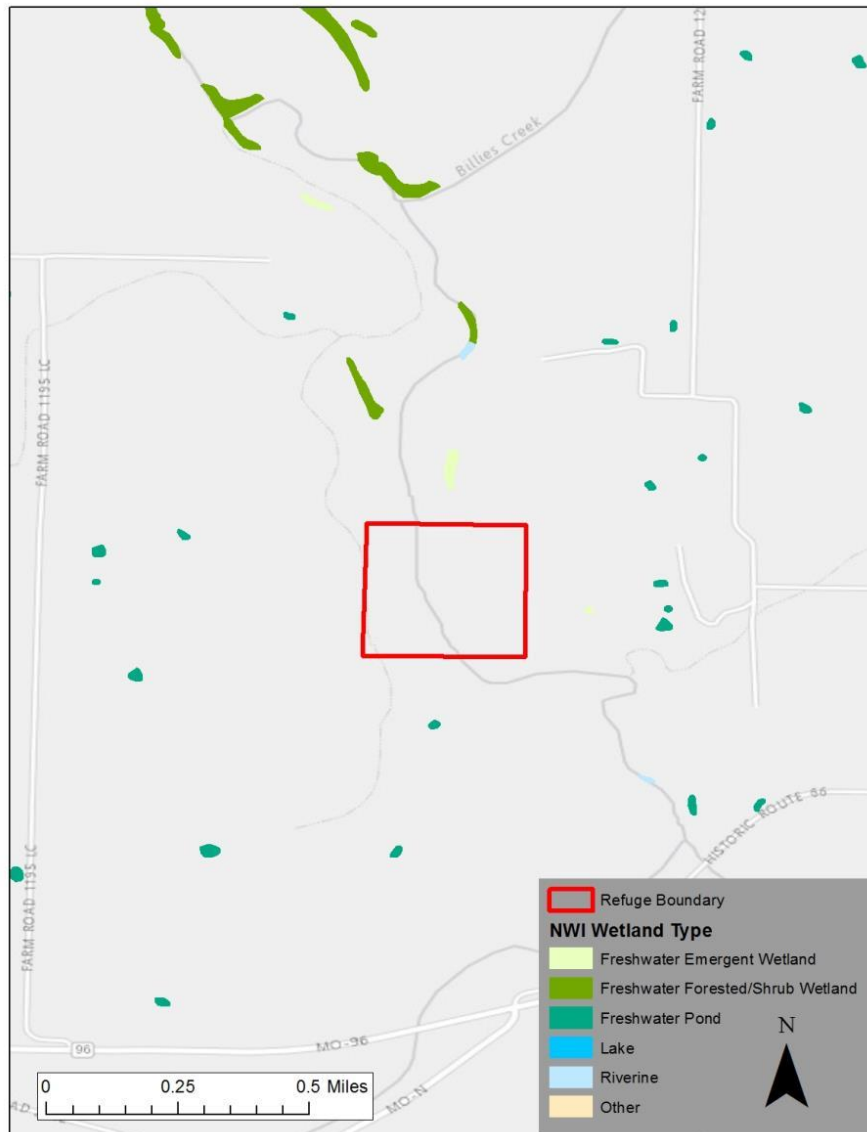


Figure 4.6: Wetland types found near OCNWR- Turnback Cave Unit

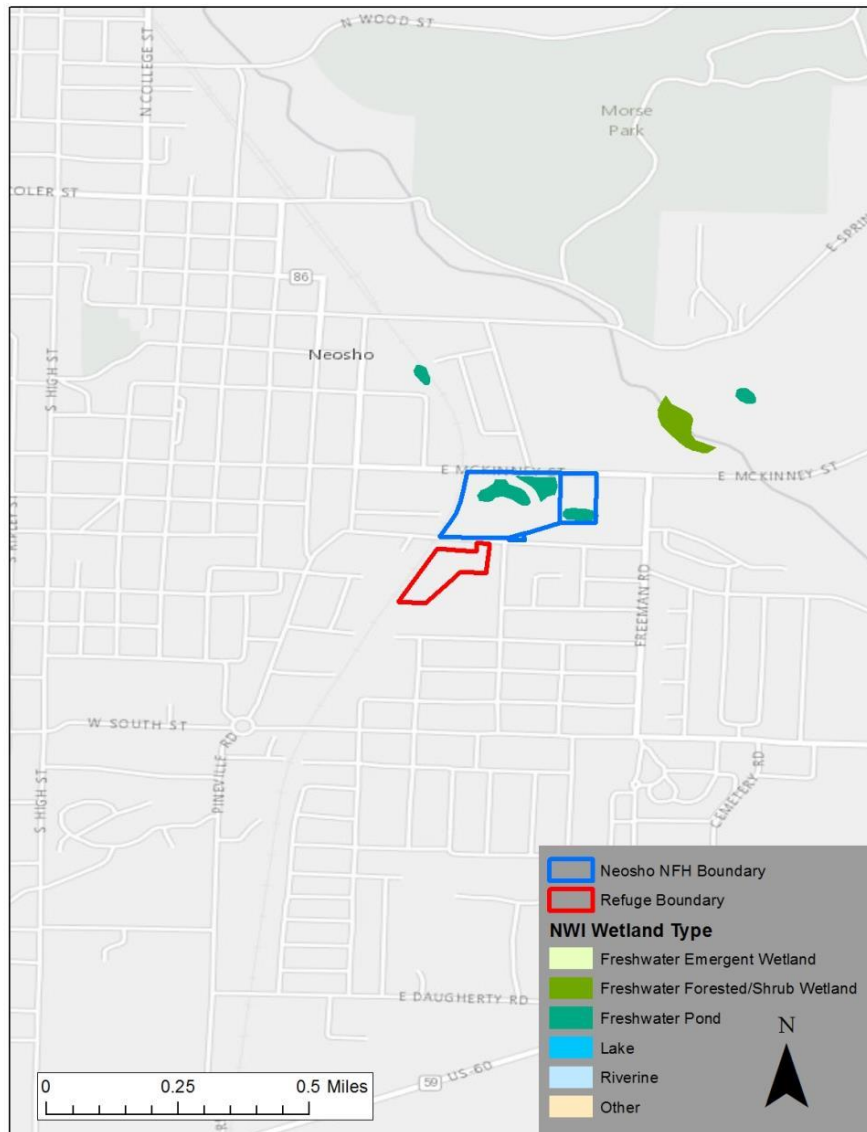


Figure 4.7: Wetland types found at OCNWR- Hearrell Spring Unit

4.3 National Hydrography Dataset

The National Hydrography Dataset (NHD) is a vector geospatial dataset including information about the nation's lakes, ponds, rivers, streams, and other water features, part of the USGS's National Map. Within MNWR, PKNWR, and OCNWRs approved boundaries, the flowpaths identified by the NHD can be broken down based on type. The majority of the flowpaths were considered canals/ditches and intermittent stream or rivers (Figure 4.8, Tables 4.2 and 4.3). Many of these features were too small to be named within the dataset, so the "named features" portion of the NHD is not necessarily all-inclusive, and some may be mis-categorized. While the NHD provides an approximate representation of general water flow, it does not necessarily reflect actual conditions, especially with regards to the dataset's flow direction indicators. For more information on the Refuge's source water quantity supplies see Section 5.2.

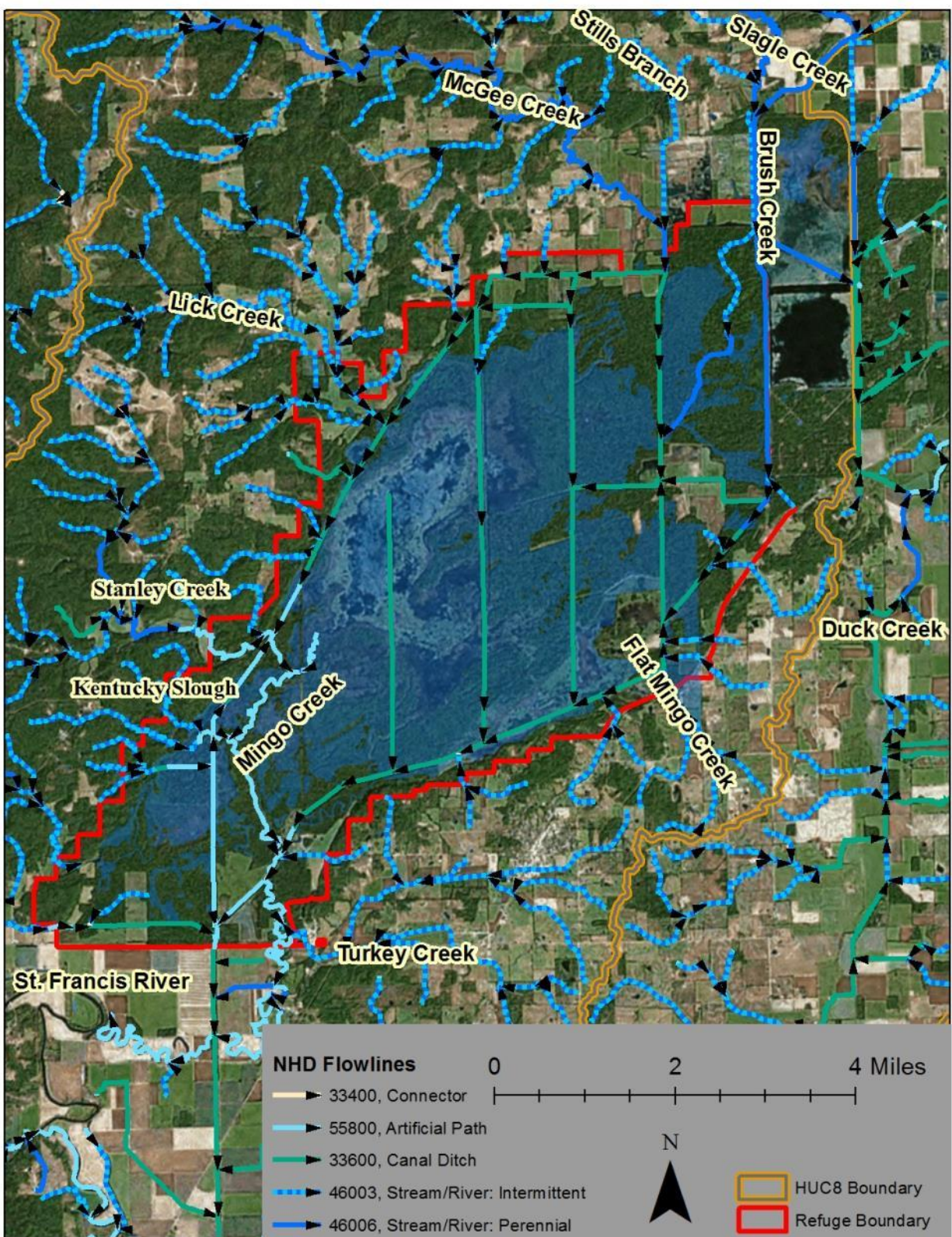


Figure 4.8. Map of NHD flowlines at MNWR

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Turkey Creek	1.65	1.86%
Stilts Branch	0.28	0.31%
Stanley Creek	2.00	2.25%
Mingo Creek	6.47	7.26%
McGee Creek	0.17	0.19%
Lick Creek	1.43	1.60%
Kentucky Slough	1.76	1.98%
Flat Mingo Creek	0.55	0.62%
"Unnamed"	74.77	83.94%
Total	89.08	100.00%

Table 4.2: NHD flowlines found at Mingo NWR

Name	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Stream/River Perennial	6.75	7.57%
Stream/River Intermittent	31.27	35.10%
Artificial Path	15.21	17.07%
Connector	0.05	0.06%
Canal/Ditch	35.81	40.20%
Total	71.95	100.00%

Table 4.3: NHD flowline types found at Mingo NWR

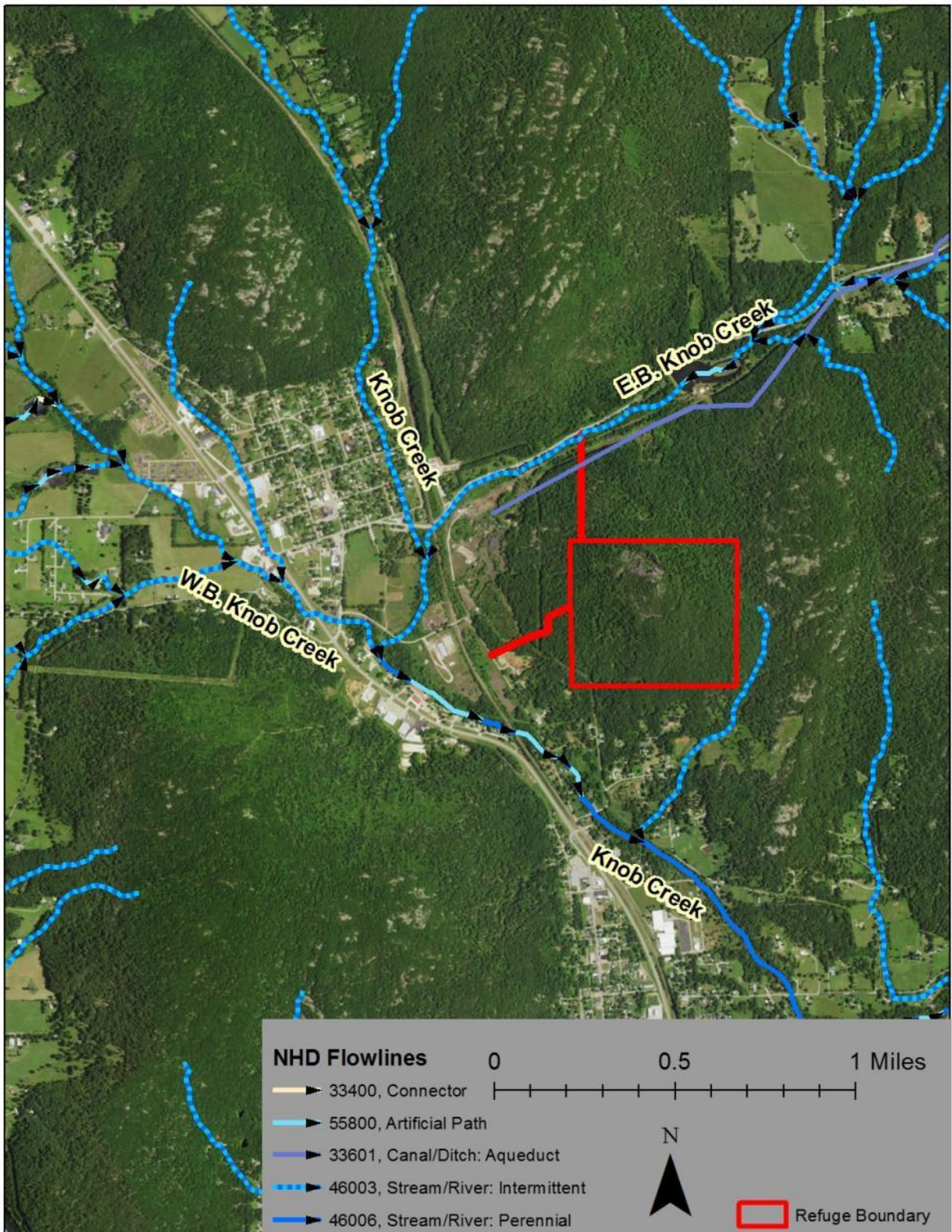


Figure 4.9: Map of NHD Flowlines near PKNWR

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
East Branch Knob Creek	0.56	22.94%
Knob Creek	0.73	29.95%
Unnamed	1.15	47.11%
Total	2.43	100%

Table 4.4: NHD flowlines found at PKNWR

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Artificial Path	0.41	16.71%
Canal/Ditch: Aqueduct	0.57	23.35%
Stream/River: Intermittent	1.28	52.80%
Stream/River: Perennial	0.17	7.15%
Total	1.43	100.00%

Table 4.5: NHD flowline types found at PKNWR

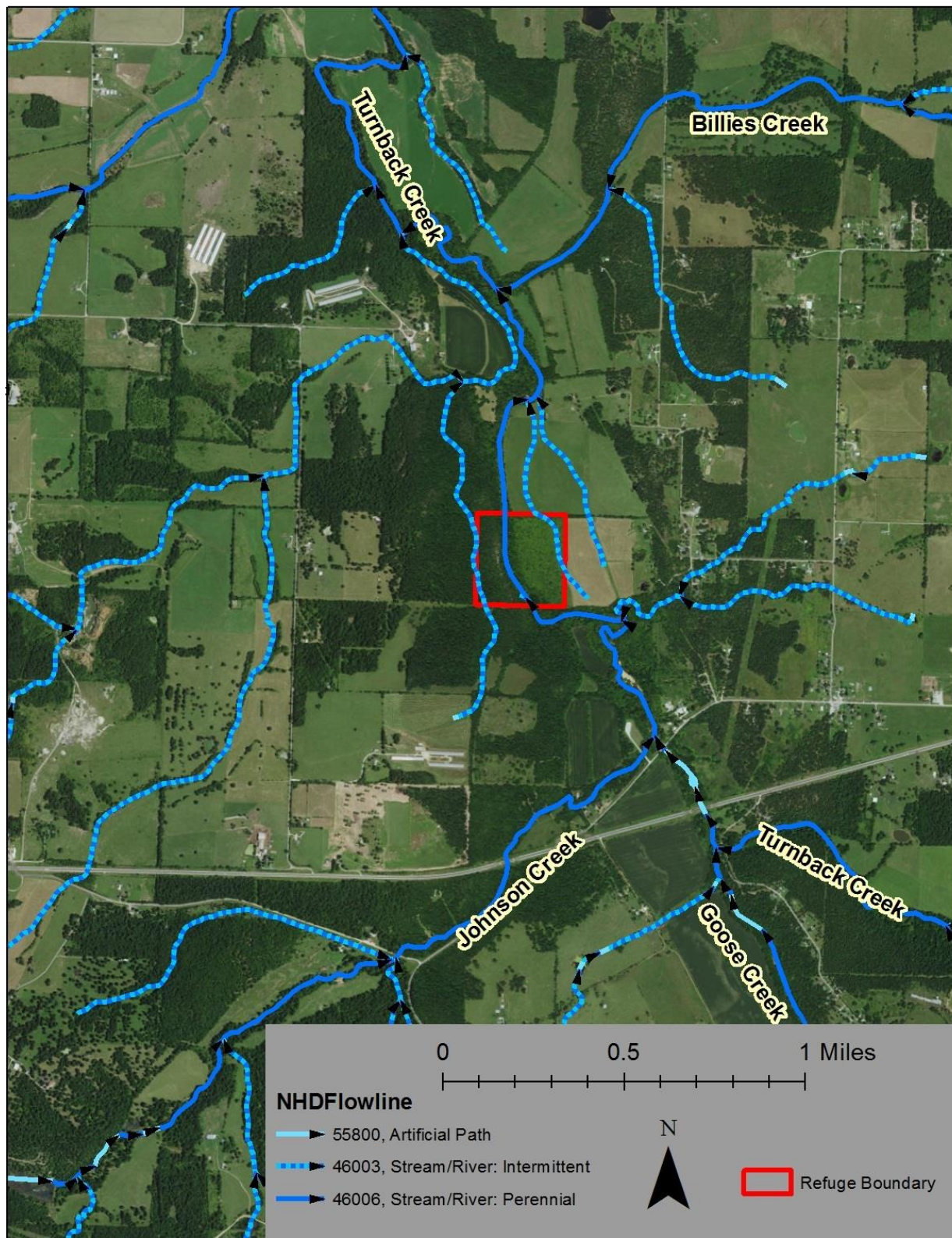


Figure 4.10: NHD Flowlines found at OCNWR-Turnback Cave Unit

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Turnback Creek	1.09	34.99%
Unnamed	2.02	65.01%
Total	3.10	100.00%

Table 4.6: NHD flowlines found at OCNWR- Turnback Cave Unit

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Stream/River: Intermittent	2.02	65.01%
Stream/River: Perennial	1.09	34.99%
Total	1.43	100.00%

Table 4.7: NHD flowline types found at OCNWR- Turnback Cave Unit

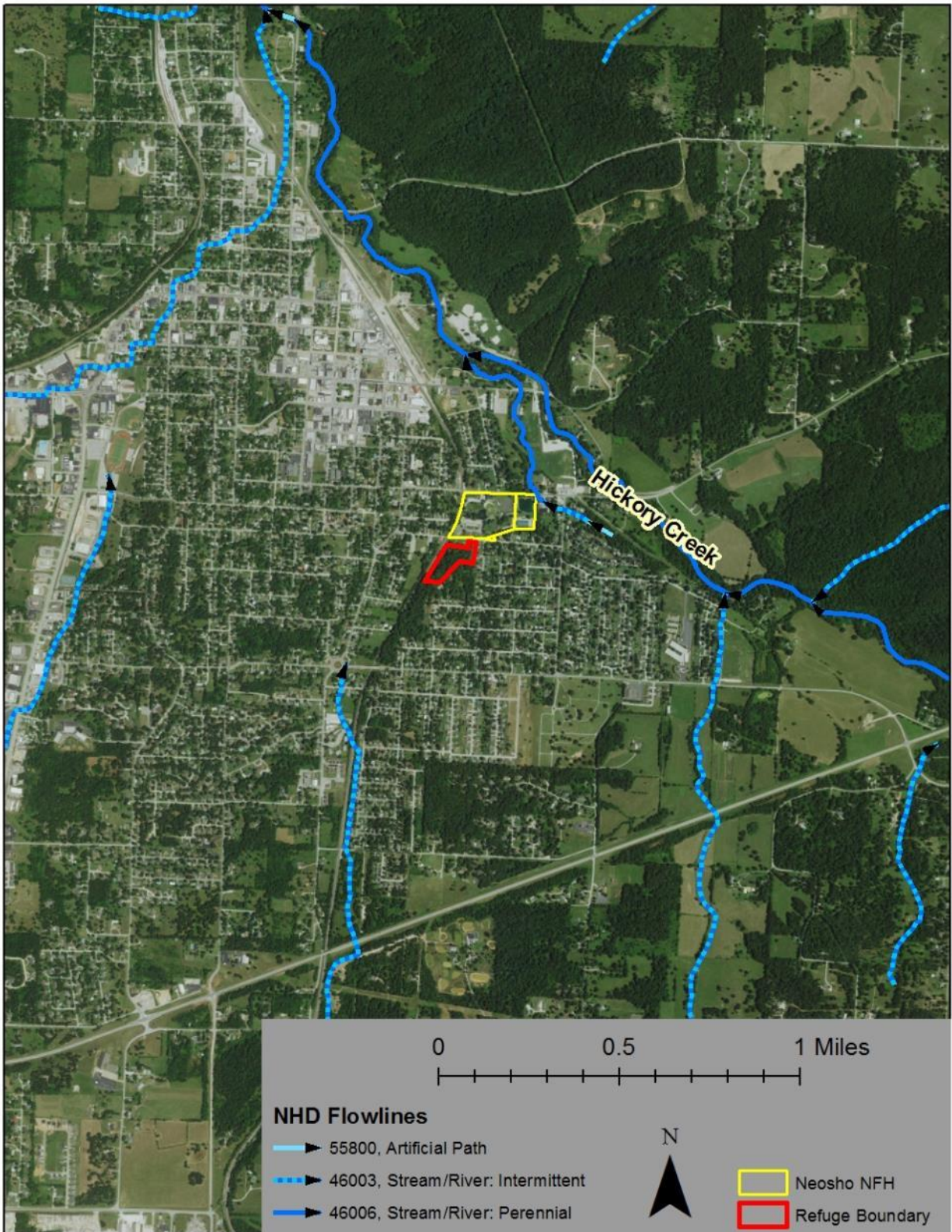


Figure 4.11: NHD flowlines found near OCNWR-Hearrell Spring Unit

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Stream/River: Intermittent	0.10	66.66%
Stream/River: Perennial	0.05	33.33%
Total	0.15	100.00%

Table 4.8: NHD flowline types found near OCNWR-Hearrell Spring

Description	Total Miles (within acq. Boundary + 0.25 mile buffer)	Percent
Unnamed	0.15	100.00%

Table 4.9: NHD flowline types found near OCNWR-Hearrell Spring

5. Water Resource Monitoring

The WRIA identified historical and ongoing water resource related monitoring on or near the Refuges. Ground and surface water stations were considered relevant if located within the Refuges' HUC-10 and/or drainage areas adjacent to Refuge properties. Relevant sites were evaluated for applicability based on location, period of record, extensiveness of data, sampling parameters, trends, and dates of monitoring. Water resource datasets collected on the Refuges can be categorized as water quantity or water quality monitoring of surface or groundwater.

Water quantity monitoring typically involves measurements of water level and/or volume in a surficial water body or subsurface aquifer. Water quality can include laboratory chemical analysis, deployed sensors or biotic sampling such as fish assemblages or invertebrate sampling. Biotic sampling is often used as an indicator of biological integrity, which is a measure of stream purpose attainment by state natural resources management organizations. Potential water quality threats may be identified by comparing monitoring data with recommended standards.

5.1 Water Monitoring Stations and Sampling Sites

Several resources offer water quality and quantity datasets relevant to the Refuge and were utilized in the creation of MNWR, PKNWR, and OCNWR's water monitoring site inventory. For example:

- Data for historical sampling locations can be retrieved through the EPA STORET (STOrage and RETrieval; <http://www.epa.gov/storet>) database. This data warehouse is a repository for water quality, biological, and physical data used by state environmental agencies, EPA and other federal agencies, universities, and private citizens.
- Water quality data for active and inactive monitoring sites can also be accessed from the USGS National Water Information System (NWIS) database (<http://www.waterqualitydata.us>).
- Datasets from seven water quantity monitoring locations at MNWR (Figure 5.1), are maintained by the USFWS and stored in the regional water monitoring WISKI database. However, they require further records management work before the data can be interpreted.
- The WRIA identified fifteen monitoring sites that are considered applicable to the Refuges' water resources, including twelve surface water monitoring sites and three groundwater monitoring stations (see Appendix A).
- A list of 202 identified inactive sites that are relevant, but not directly applicable to the resources of concern, was also created and will be loaded into the ECOS WRIA application (<https://ecos.fws.gov/wria>). This data is available upon request.

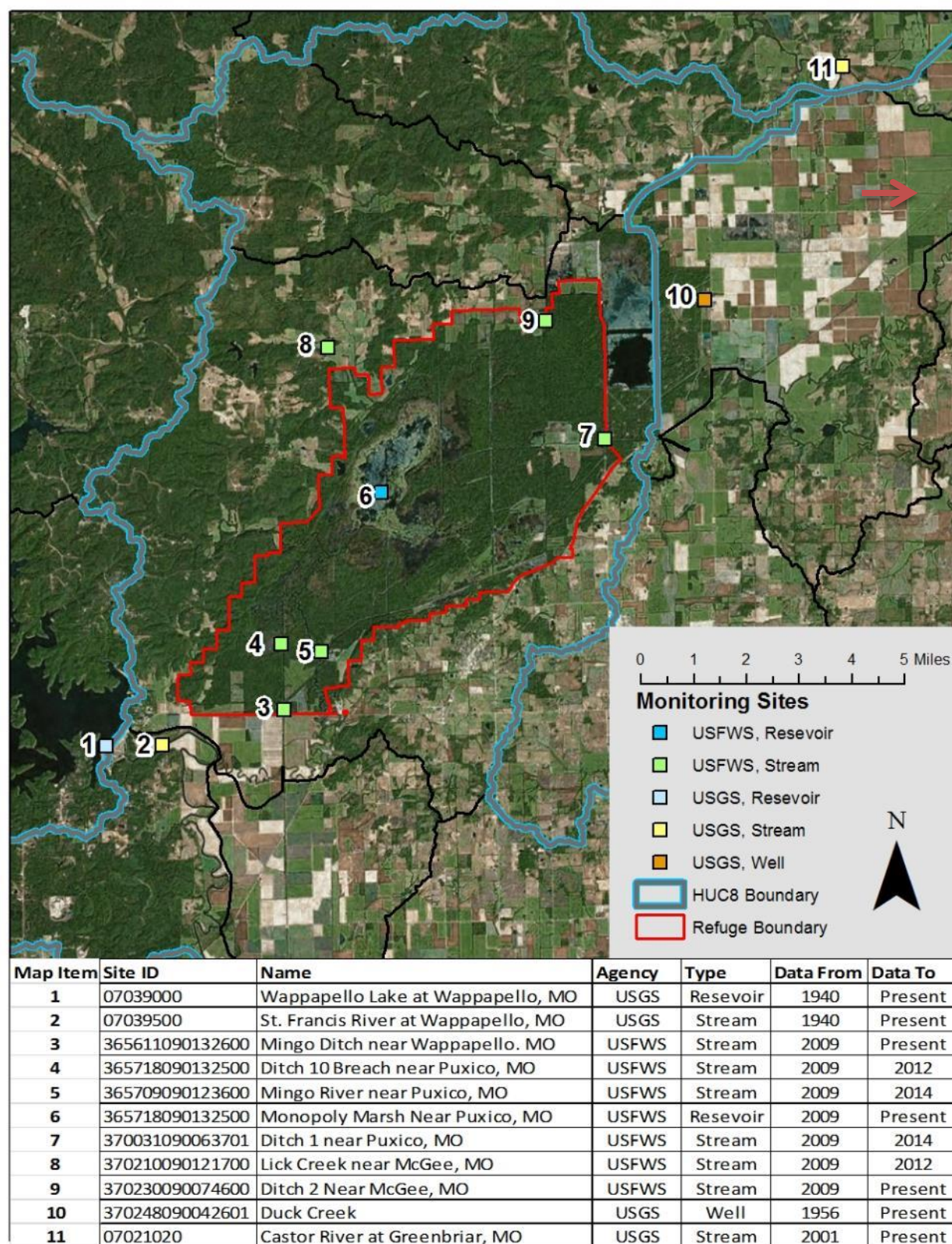


Figure 5.1: Locations of applicable USGS and FWS water monitoring stations at Mingo NWR

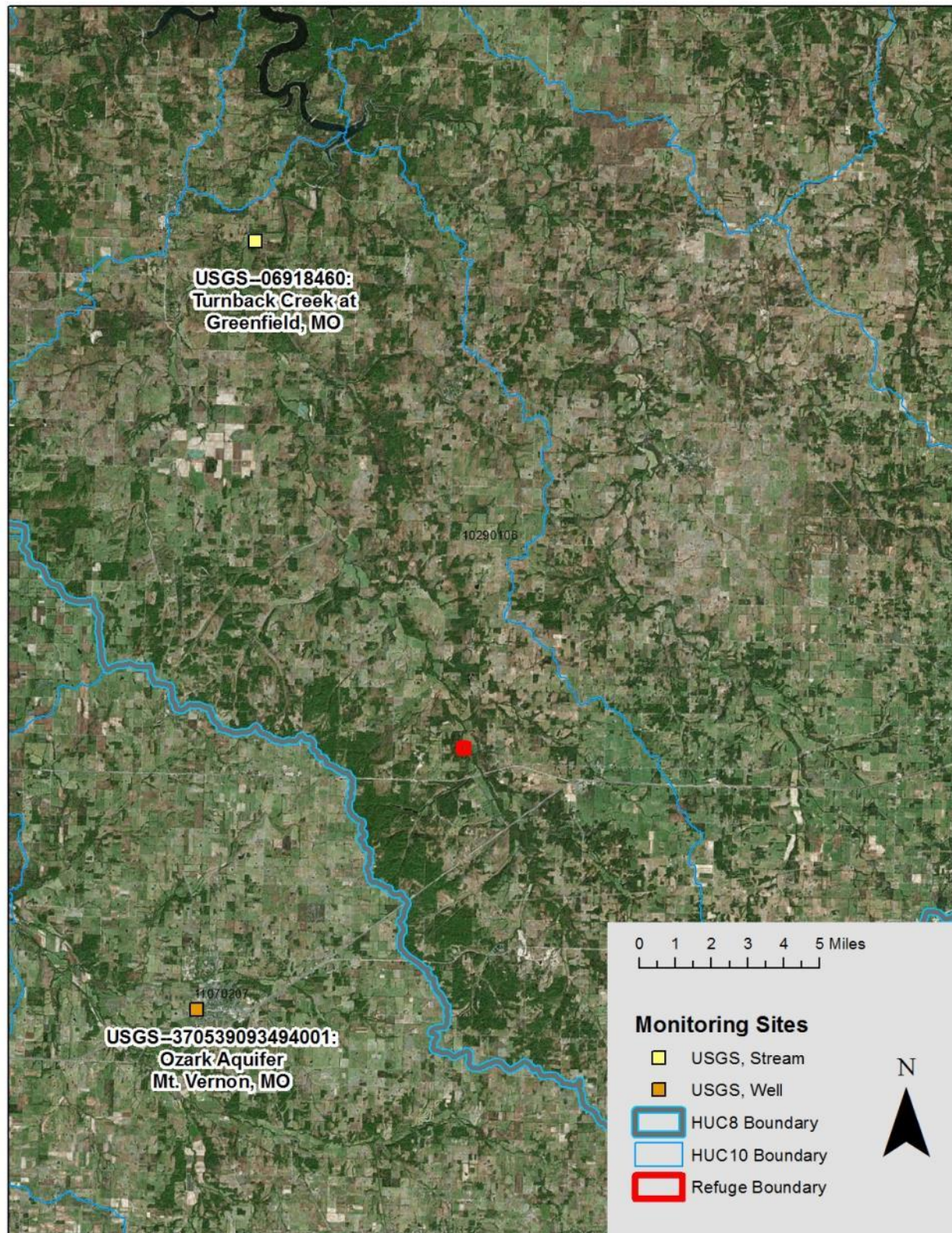


Figure 5.2: Locations of applicable USGS and FWS water monitoring stations for Ozark Cavefish NWR- Turnback Cave Unit

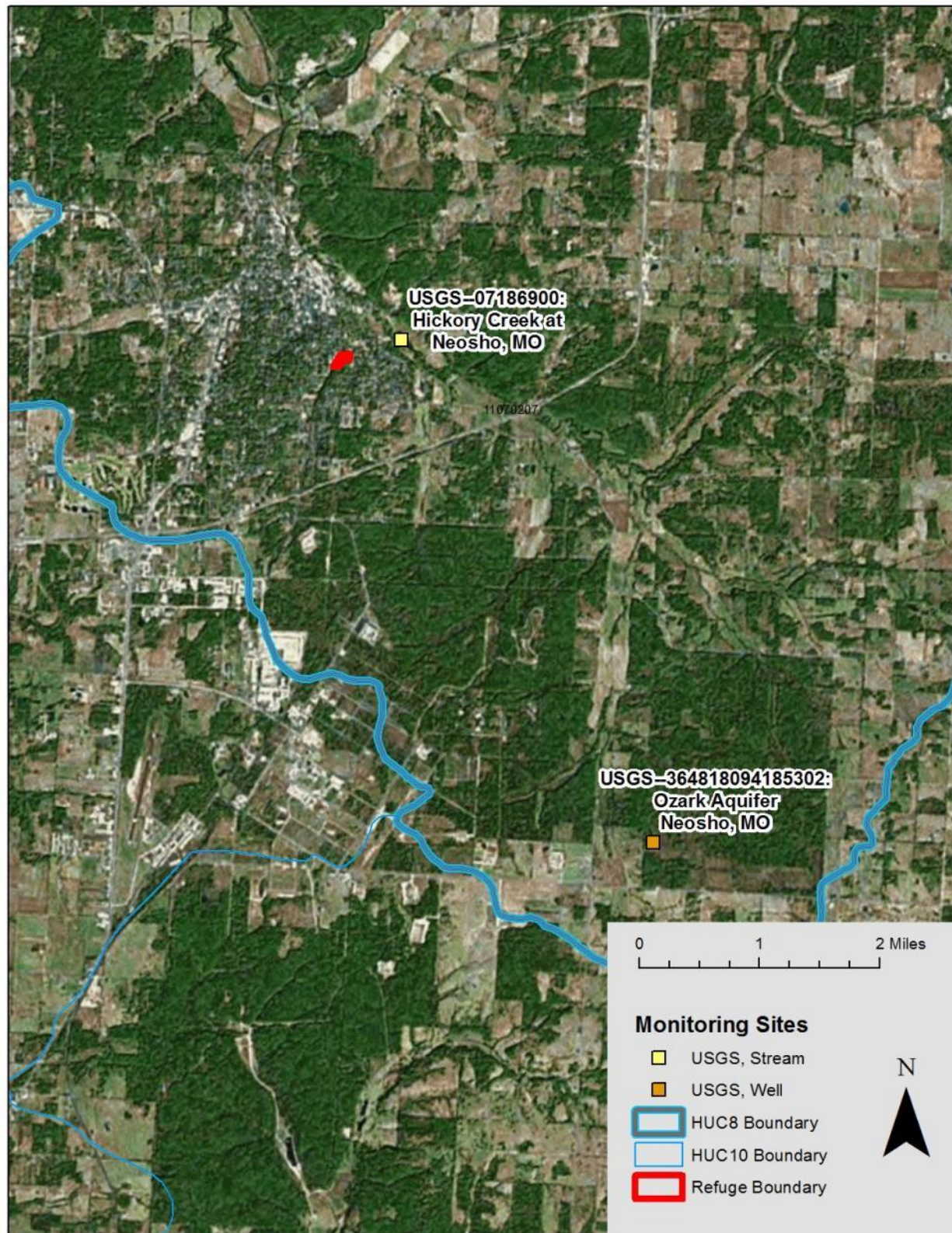


Figure 5.3: Locations of applicable USGS and FWS water monitoring stations for Ozark Cavefish NWR- Hearrell Spring Unit

5.2 Surface Water Quantity

Mingo NWR

Mingo NWR lies in the middle of the Mingo Swamp HUC-10 watershed region and covers over 40% of the watershed's area. There are numerous small tributaries that converge on the Refuge's vast and flat landscape from the relatively steep surrounding highlands. All surface waters exit the Refuge through a single water control structure. It is difficult to quantify or predict water levels and volumes on the Refuge due to the large number of small tributaries, the large number of water control structures, and the historically highly altered hydrology. There have been projects in the past that looked to build a water management model for Refuge staff to better predict and prepare for changing water conditions (Woods 2004, Taylor 2014). Numerous gaging stations have been set up on the Refuge and its tributaries by FWS staff from 2009 until present (see below) and the analysis of this data should help provide more insight on the complex hydrologic relationships in this system.

Monopoly Marsh near Puxico, MO

Monopoly Marsh ([FWS-365718090132500](#)) is the largest wetland unit at Mingo NWR. The period of record for this site runs from July 2009 until present (Figure 5.1). This gaging location is very important to Refuge staff because it serves as an indicator of water levels in the Refuge's largest contiguous unit, Monopoly Marsh. Data for this station can be accessed remotely by refuge staff through the use of NOAA's Geostationary Operation Environmental Satellite (GOES) system. Monopoly Marsh is a managed system and except for extreme flood or drought, the stage record mainly reflects water level management actions and response to localized rainfall. Over the period of record, the water levels in Monopoly Marsh have been highly variable, with a difference of 10 feet between the highest and lowest recorded values. The hydrograph shows multiple peaks in many years on record, but in general, the stage in Monopoly Marsh is highest in the winter and spring, and lowest in late summer and fall (Figure 5.4).

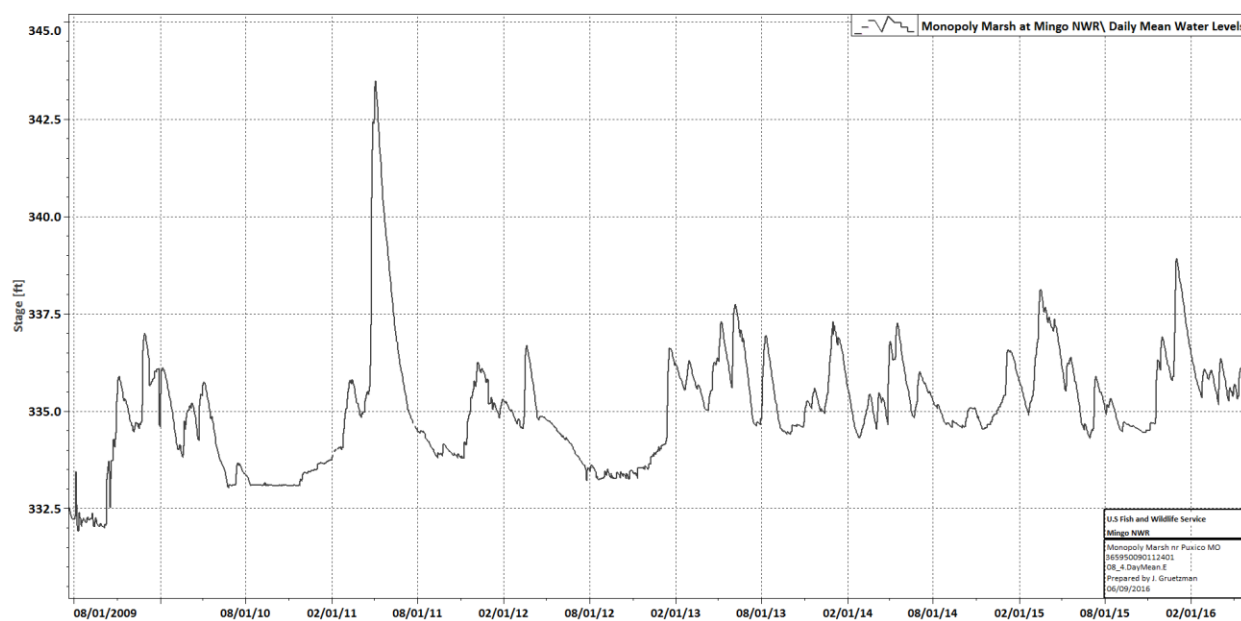


Figure 5.4: Daily averaged stage (2009-2016) for ([FWS-365718090132500](#)), Monopoly Marsh near Puxico, MO

Brush Creek near Puxico, MO

Brush Creek is a watershed of approximately 12,233 acres (Section 3.1), that lies to the north of Mingo NWR's easternmost boundary and flows directly into the Refuge. Just upstream of the Refuge Brush Creek is met by Slagle Creek and then flows a short distance before becoming what is known as Ditch 1 within the Refuge boundaries (Figure 5.5). Ditch 1 runs along the Refuge's eastern boundary, and the water is shared between Mingo NWR and the MDC Duck Creek CA. Water in Ditch 1 can be diverted to Pool 8 or Moist Soil Units on the eastern side of the refuge, or else it can flow downstream and meet with Ditch 2 (Section 4.1). Slagle Creek, which forms the eastern half of the Brush Creek catchment, has a diversion channel which connects it with Castor River (Figure 5.5). Water can either be diverted from the Castor into Slagle Creek or from Slagle into the Castor depending on local flood conditions. Flow gaging data for Brush Creek exists on Ditch 1 within the Refuge (FWS-370031090063701) for 2009-2014 (Figure 5.1). However, it requires analysis and reporting before it can be usable.

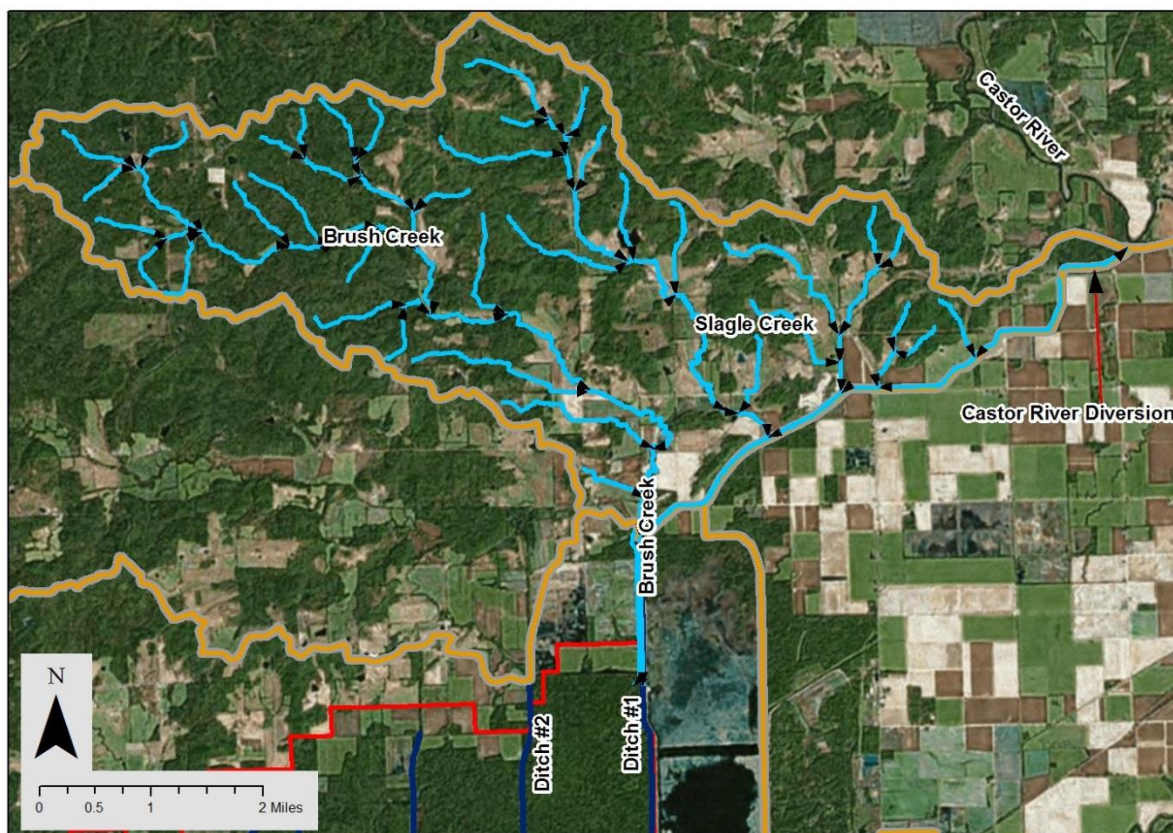


Figure 5.5: The Brush Creek watershed (north of Ditch 1)

McGee Creek near McGee, MO

McGee creek is Mingo NWR's largest single tributary at approximately 13,219 acres (Section 3.1). It lies to the north of the Refuge and west of Brush Creek. McGee Creek includes several smaller tributaries such as Rocky Creek, DeCelis Branch, Gribler Creek, and Stilts Branch. Just downstream of the confluence of McGee Creek and Stilts Branch, the Creek enters the Refuge and forms what is known as Ditch 2 (Figure 5.6). Ditch 2 serves a major source of water quantity on the Refuge providing water to much of the Units in its eastern half. Ditch 2 flows downstream into Ditch 11 (Section 4.1). Gaging operations on this Creek are currently active in the Ditch 2 portion within Refuge boundaries (USFWS-370230090074600) running from 2009 to present (Figure 5.1). However, this data requires analysis and reporting before it

is usable.

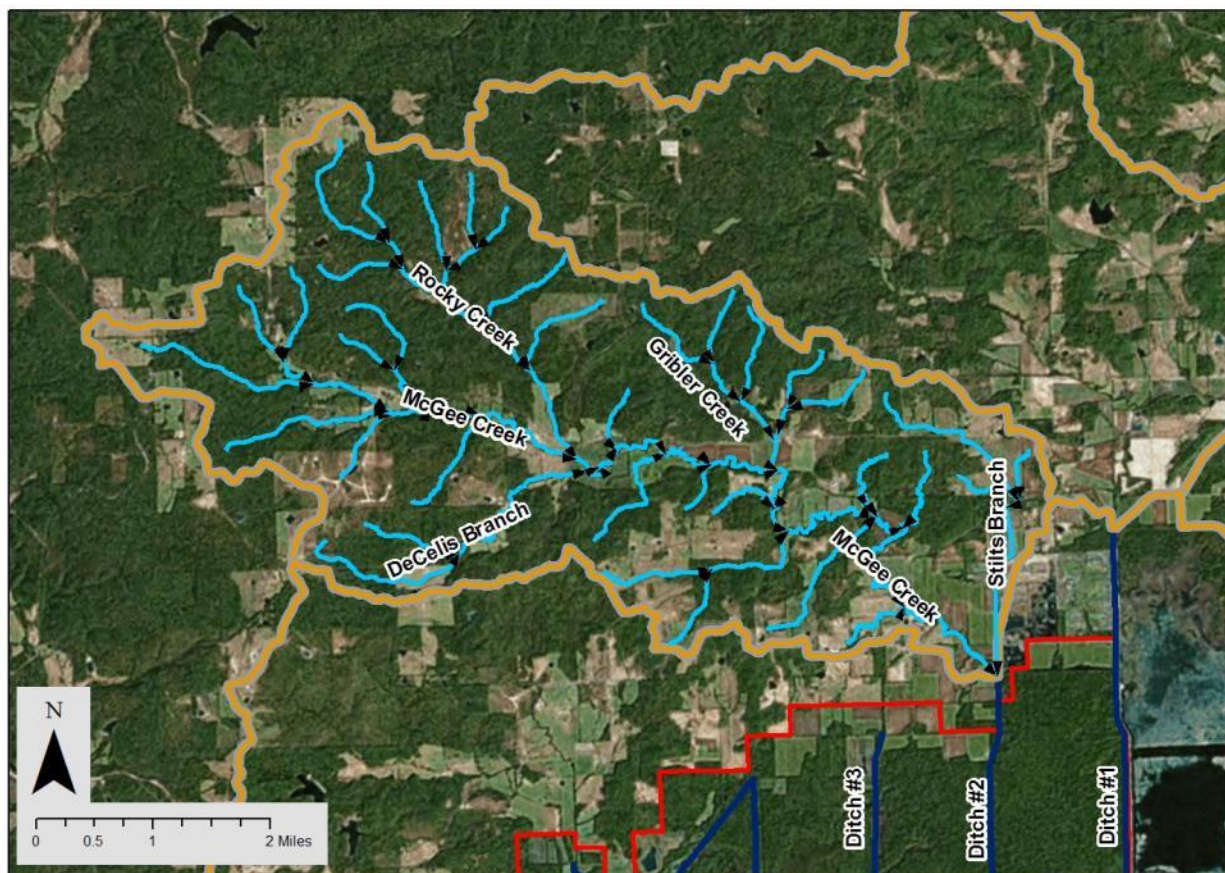


Figure 5.6: The McGee Creek watershed (northwest of Ditch 2)

Lick Creek near McGee, MO

Lick lies to the southwest of McGee Creek northwest of Mingo NWR's boundary. It is smaller than either McGee or Brush Creek. This tributary flows into Mingo's Ditch 10 and supplies most of the water to Monopoly Marsh, the Refuge's largest unit (Figure 5.7). The water from this tributary ultimately reaches Ditch 11 by way of Ditch 5 or Ditch 6. Lick Creek falls within the Mingo Swamp HUC-12 but at this time, its drainage area has not been determined. Gaging data exists for Lick Creek (FWS-370210090121700) from 2009 until 2012 (Figure 5.1). However, this data needs to be analyzed and reported before it is usable.

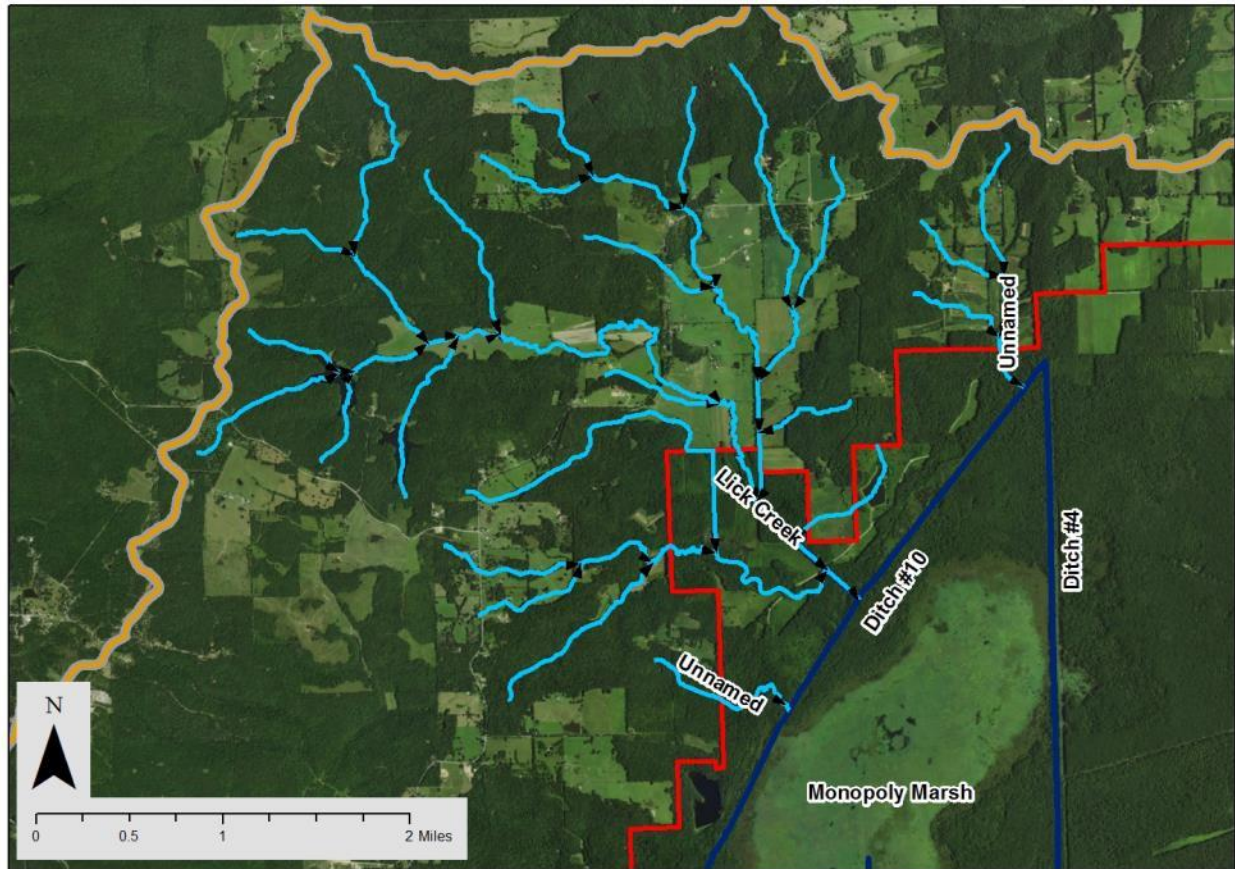


Figure 5.7: The Lick Creek watershed (northwest of Ditch 10)

Stanley Creek near Puxico, MO

Stanley Creek is another important tributary of Mingo NWR that lies to the west of the Refuge's border. Stanley Creek has a tributary named John's Branch with which it joins upstream of the Refuge before flowing into Ditch 10 and Mingo Creek (Figure 5.8). Water entering this area from Stanley Creek is impounded in the Mingo Wilderness area. There is an earthen plug downstream in Ditch 10, and water control structures on both the upstream and downstream ends of Mingo Creek. This causes frequent and prolonged inundation in the area between Ditch 6 and Ditch 10 that is causing timber die-offs in the Wilderness area. Also in this vicinity, the smaller Kentucky Slough flows in from the West, contributing to the impounded area. Both of these catchments are contained in the Mingo Swamp HUC-12 and neither have had their drainage area calculated at this time. Both have also never had gaging operations on them.

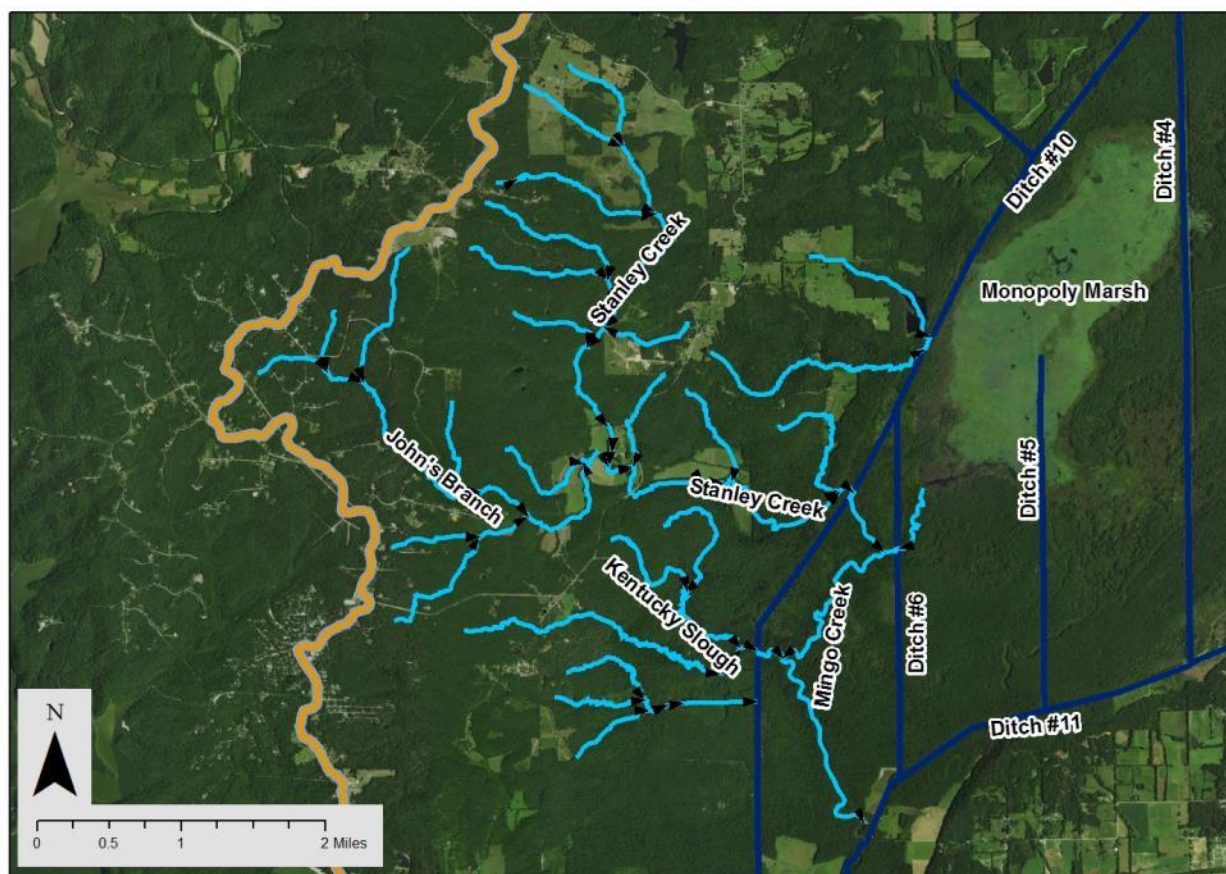


Figure 5.8: The Stanley Creek and Kentucky Slough watersheds (West of Ditch 10 and Mingo Creek)

Flat Mingo Creek near Puxico

The Flat Mingo Creek is a small tributary that drains from the south into the southwest corner of the Refuge, near the intersection of Ditch 2 and Ditch 11. The contribution of this Creek to the overall water quantity of the Refuge is very small, but it likely plays a role for management units in the Refuge's southwest area including two Moist Soil Units, and Red Mill Pond. Flat Mingo Creek falls within the Mingo Swamp HUC-12 drainage. However its drainage area is undetermined at this time.

Turkey Creek

Turkey Creek is a small intermittent drainage on the southwest end of the Refuge. It does technically flow into the Refuge, but it is downstream of all major Refuge units and water control structures, and thus likely has little if any impact on Refuge water quantity. Turkey Creek's drainage area is undetermined at this time.

Other Mingo Water Quantity Monitoring Stations

There are two other monitoring stations within the Refuge that do not include source water supply but rather measure water moving within the Refuge and exiting the Refuge (Figure 5.1). Mingo Creek at Flat Banks (FWS-365709090123600) was a gaging station on the impounded Mingo Creek that ran from 2009-2014. Data from this site requires analysis and reporting before it is usable. Ditch 10 Breach near Puxico, MO (FWS-365718090132500) was a gaging station that measured the movement of water at a lateral breach in Ditch 10 that is

downstream of the earthen plug that impounds Stanley Creek and Kentucky Slough. This site ran from 2009-2012 and the data requires further analysis before it is usable. Mingo Ditch near Wappapello, MO ([FWS-365611090132600](#)), also known as Ditch 15, is a gaging site located on the Mingo Ditch downstream of the Refuge's downstream outlet water control structure. This site measures the volume of all water exiting the Refuge in through runoff. This site was moved 200 feet upstream in 2013. Data runs from 2009 to present, but requires further analysis before it can be used.

St. Francis River at Wappapello, MO

The St. Francis River gage at Wappapello, MO ([USGS-07039500](#)) is a somewhat relevant surface water station because it represents the behavior of the St. Francis River upstream of the Refuge. The St. Francis River is the receiving water body for the Mingo Drain and can possibly affect refuge hydrology by causing a backwater effect on the Mingo Ditch during times of heavy flooding (Refuge staff, personal communication, 2016). The headwaters of the St. Francis River originate in the St. Francois Mountains in Iron County, and the river runs 225 miles to the Arkansas border (Boone 2006). The divide between the Upper St. Francis and Lower St. Francis basins is located at the Wappapello Dam, and the USGS gage 07030500 is located just downstream of this dam (Figure 5.1). At this point, the river drains 1,311 square miles of the Ozark Plateau. Figure 5.9 shows the highly regulated nature of flow at this location (note the peak in 2011).

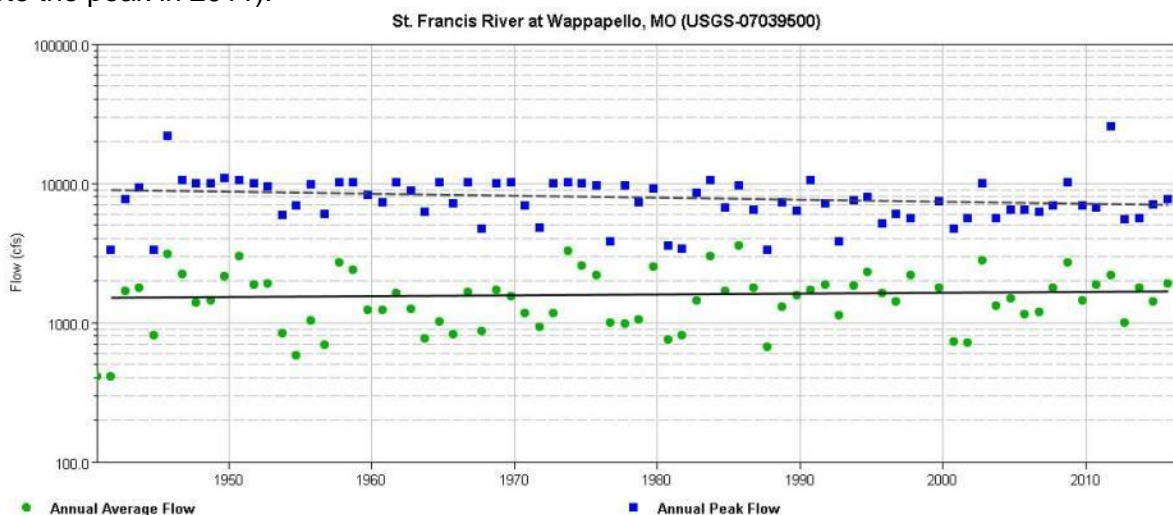


Figure 5.9: Annual peak and average discharge (1941-2015) ([USGS-07039500](#)), St. Francis River at Wappapello, MO

Castor River at Greenbrier, MO

The Castor River at Greenbrier, MO ([USGS-07021020](#)) is located just over six miles from Mingo NWR's boundaries, and is located just outside of the St. Francis River watershed (Mingo Swamp HUC-10). However, this is still an important gaging station for the Refuge because the Castor River can flood across watershed boundaries during high flood events, as often as 4-5 times per year by way of the Cato Ditch and Cato Levee (Refuge staff, personal communication, 2016), and it can also flow into the Brush Creek watershed by way of a diversion channel. Further analysis could potentially show stages on the Castor that flood into the Brush Creek system and subsequently into the Refuge. The Castor River is a tributary of the Lower St. Francis, draining into the Little River, which flows southward parallel to the St. Francis for much of its distance before joining in Arkansas. At this gaging station ([USGS-07021020](#)),

there are also over 100 water quality samples ranging from 1999 to present. However, the gaging record only includes stage data from 2001 until present.

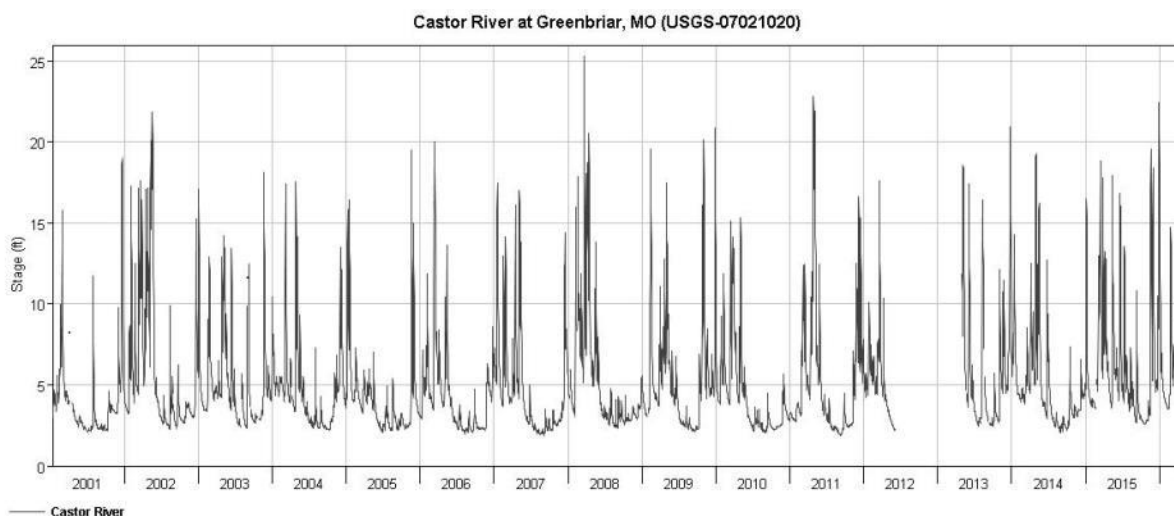


Figure 5.10: Daily averaged stage (2001-2016) for [USGS-07021020](#), Castor River near Greenbriar, MO

Turnback Creek near Greenfield, MO

Turnback Creek is the receiving body of water for the Turnback Cave, and is the largest body of water passing through the Ozark Cavefish NWR. The Turnback Creek gage near Greenfield, MO ([USGS-06918460](#)) is located approximately 14.5 miles downstream from the Refuge, but serves as the only active gaging station directly on the creek. Gaging records from this site run from 1965 until present. This gaging site is located just upstream of where Turnback Creek empties into the Stockton Reservoir and Sac River, which in turn serves as a tributary to the Osage River. Turnback Creek has a known history of flashy storm flows and large floods. Parts of the Creek contain losing reaches, meaning that some of the in-stream flow is lost to the groundwater aquifer due to underlying karst topography. There are over 197 miles of stream in the Turnback HUC10 watershed (Kiner et al. 2015).

The period of record hydrograph for Turnback Creek shows an extremely flashy stream system, with low flows nearing 0 cfs and the highest flood flows topping 20,000 cfs (Figure 5.11). The largest floods on record appear in 1993, 2015, and 1986. Average monthly flows show that flows are highest March through May and lowest August through October (Figure 5.12). However, average monthly peak flows show there may be multiple flood peaks per year, occurring in May, September, and December. Trends in annual average discharge and peak flows both show an increase over time, however these increases are not statistically significant (Figure 5.13). The flow exceedance curve for Turnback Creek is indicative of highly flashy discharge patterns. The Q10 of 565 cfs is over 18 times higher than the Q90 of 30 cfs. The Q50 is just over 100 cfs, and very high flows (Q1) are 5,000 cfs and higher (Figure 5.14).

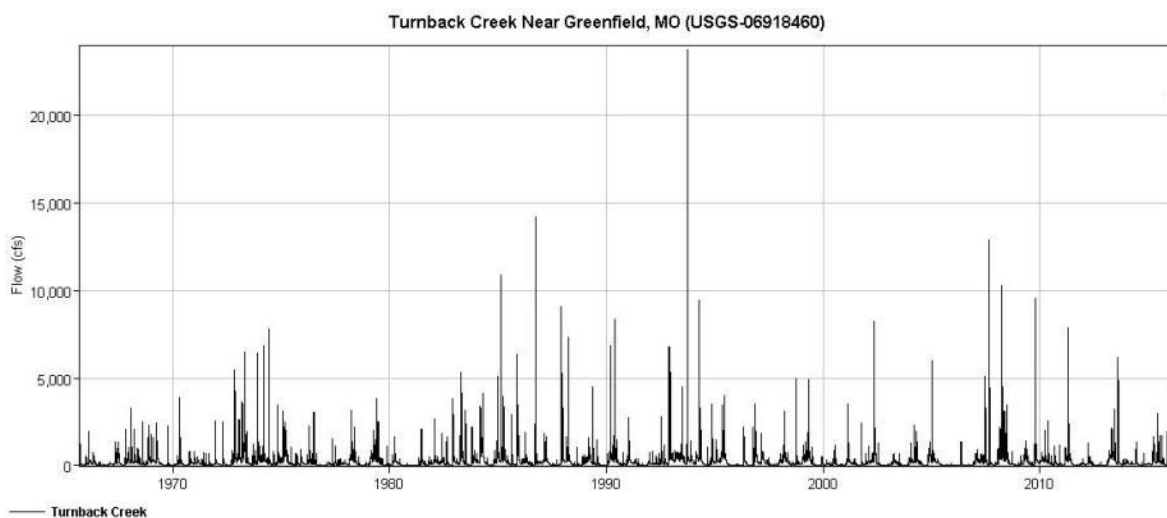


Figure 5.11: Daily averaged flow (1965-2016) for [USGS-06918460](#), Turnback Creek near Greenfield, MO

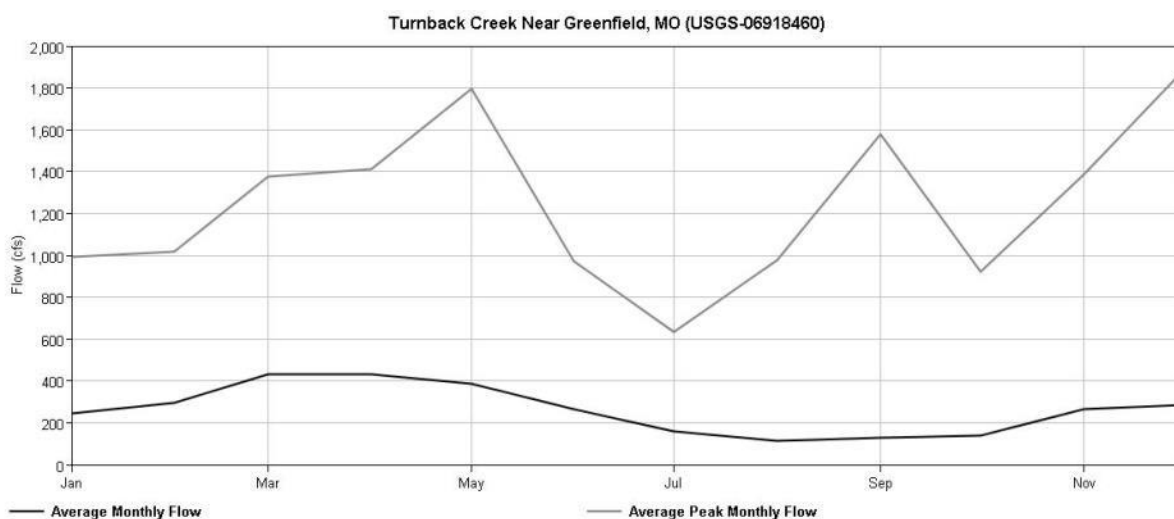


Figure 5.12: Average monthly flow (1965-2015) for [USGS-06918460](#), Turnback Creek, near Greenfield, MO

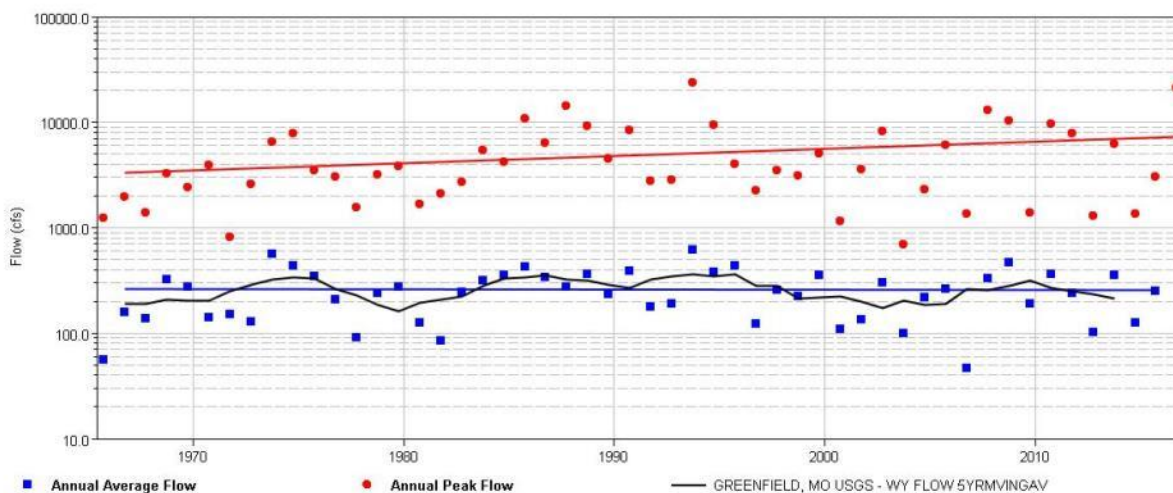


Figure 5.13: Average annual and peak flow (1965-2015) for **USGS-06918460**, Turnback Creek, near Greenfield, MO

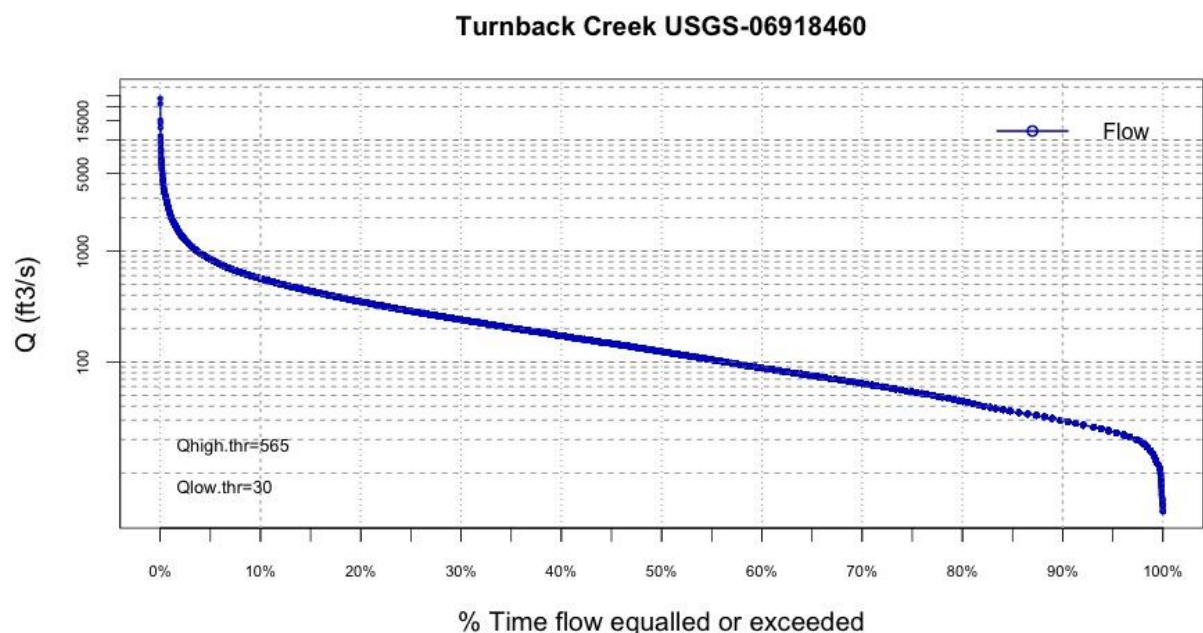


Figure 5.14: Flow exceedence curve (1965-2015) for **USGS-06918460**, Turnback Creek, near Greenfield, MO

Flood Frequency	Discharge (cfs)	Stage NGVD29 Feet
2-year	7,017	887.0
5-year	14,380	890.6
10-year	21,040	892.7
25-year	31,670	894.9
50-year	41,330	896.4
100-year	52,600	897.7
200-year	65,650	899.0

Table 5.1: Flood frequency analysis results using PeakFQ (1966-2016) for [USGS-06918460](#), Turnback Creek near Greenfield, MO

Hickory Creek Near Neosho, MO

Hickory Creek is the receiving body of water for Hearrell Spring and Neosho NFH. The gaging site in Neosho, MO ([USGS-07186900](#)) is located just over a half mile from Hearrell Spring itself. The creek does not directly affect refuge land, since it is a receiving water of the Spring's discharge. But, it can provide useful information regarding the relationship between surface and groundwater in the Springfield Groundwater Province. Hickory Creek is located in the headwaters of the Spring River HUC-8, which is a tributary of the Neosho River and Arkansas River. There is a short period of record for this gaging site, from October 2012 until present.

Daily average flows for Hickory Creek show a highly flashy stream, almost intermittent in nature. The flow ranges from close to zero to several hundred cfs. During 2014 there were several small flood peaks of less than 50 cfs, while 2013 and 2015 show much higher flood peaks in the spring ranging from around 400 to 900 cfs (Figure 5.15). Average monthly flows are highest in May, are moderately high flows from March through July, and then are very low (around 15 cfs) or less throughout the rest of the year (Figure 5.16). A flow exceedance curve for Hickory Creek shows a Q10 of around 40 cfs, a Q90 of 2.5 cfs, and a Q50 of 10 cfs (Figure 5.17).

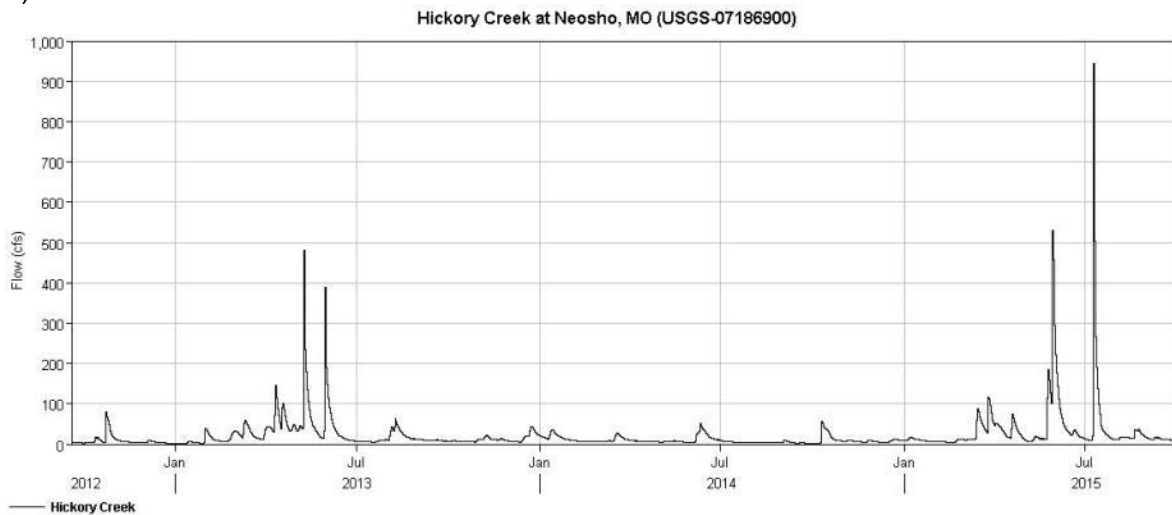


Figure 5.15: Daily averaged flow (2012-2016) for [USGS-07186900](#) Hickory Creek near Neosho, MO

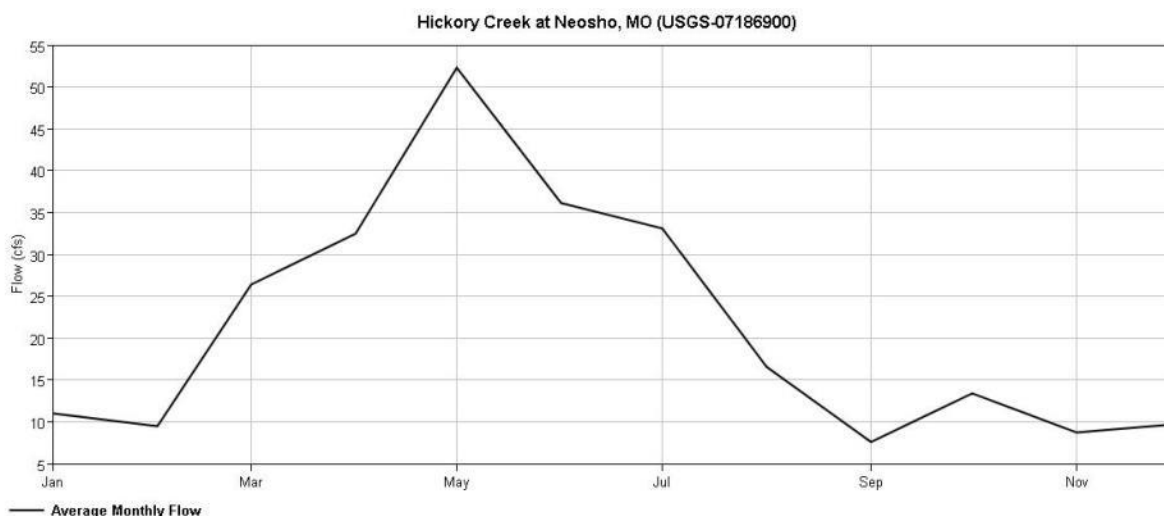


Figure 5.16: Monthly average flows (2012-2016) for [USGS-07186900](#), Hickory Creek near Neosho, MO

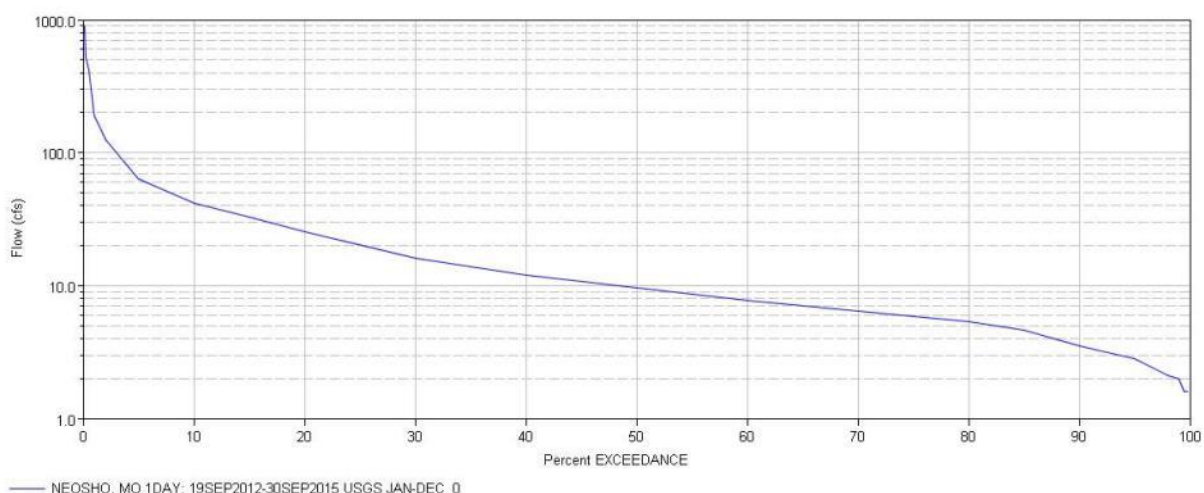


Figure 5.17: Flow exceedance curve (2012-2016) for [USGS-07186900](#) Hickory Creek near Neosho, MO

5.3 Groundwater Levels

There are three different USGS groundwater monitoring wells that are pertinent to Mingo and Ozark Cavefish NWR's (Figures 5.1-5.3). Pilot Knob NWR does not have any groundwater monitoring sites nearby. Duck Creek ([USGS-370248090042601](#)) is the closest groundwater monitoring site to Mingo NWR and records water levels in the Mississippi Valley alluvium, which is reported as an abundant aquifer near to the ground's surface (Heitmeyer et al. 2006). There are two monitoring wells relevant to Ozark Cavefish NWR. Ozark Aquifer near Mt. Vernon, MO

([USGS-370539093494001](#)) is the closest station to Turnback Cave, and Ozark Aquifer near Neosho, MO ([USGS-364818094185302](#)) is closest to Hearrell Spring.

Duck Creek

The Duck Creek groundwater monitoring site is located just two miles from Mingo NWR's borders in the adjoining Duck Creek Conservation Area. The ground surface of the well is at 344 feet NGVD29. The period of record for monitoring at this site is both continuous and extensive, dating from 1956 until present, with only a small gap in the late 1980s. This long period of record provides excellent insight into groundwater level dynamics in the area. What is first apparent is the annual fluctuation in groundwater level, but examining the 5-year moving average reveals multi-decadal oscillations in groundwater as well (Figure 5.18). Monthly average groundwater depths reveal a relatively consistent pattern of water levels over the year. Groundwater is highest in March and April at around a depth of just under five feet. From May to June the groundwater begins to drop significantly but by July through October, groundwater is fairly low at an average depth of between 8.5 and 9.5 feet. By November, levels begin rising again and continue to do so throughout the winter (Figure 5.19). Examining long term records for the Duck Creek gages reveals some interesting trends. While average annual groundwater levels have remained fairly constant, the maximum depths have increased and the minimum depths have decreased (Figure 5.20). This is indicative of increasing variability in the annual fluctuations of groundwater levels at the site. Perhaps this can be expected to continue as a trend into the future for the groundwater resources in the area.

Mt. Vernon Ozark Aquifer

The Mt. Vernon Ozark Aquifer groundwater well has a relatively recent installation in 2007. The ground surface elevation for this well is 1,215 feet NGVD29. This site is in the Ozark Plateau aquifer system, and was drilled into Cotter-Jefferson City Dolomite formation. There are two main items to note for this location. First, the depths for this aquifer are deep beneath the ground's surface, as much as over 200 feet (Figure 5.21). The second is that the groundwater level at this site is highly variable both from year to year, and even within years. For instance in 2012 (a drought year), the aquifer water level fell almost 45 feet over the course of the year, and there does not appear to be as strong of a year to year pattern.

Neosho Ozark Aquifer

The Neosho Ozark Aquifer groundwater well was installed around the same time period as the Mt. Vernon well and is located approximately 33 miles southwest. It is located in both the same aquifer type as well as the same substrate. Despite the relatively close proximity, the two sites display very different patterns over the 8-year period of record. While the Neosho site is deeper than the Mt. Vernon site, it displays much less variability on an inter- and intra-annual basis (Figure 5.23). However, it does display a long term decreasing trend from the beginning of record to present. The greatest groundwater depth was 320 feet, which occurred in 2014.

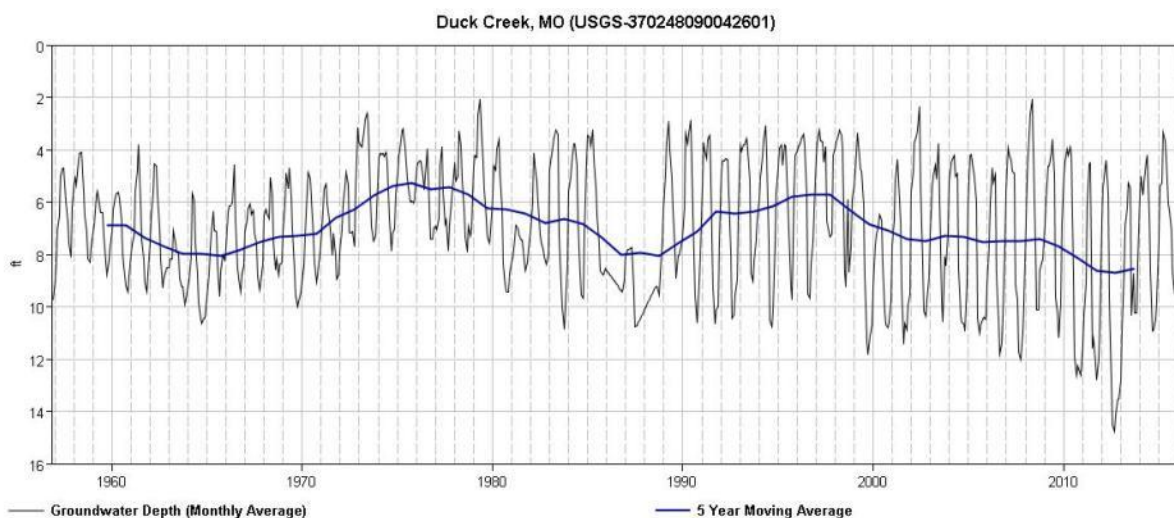


Figure 5.18: Daily average groundwater depth with 5-year moving average (1957-2016) for Duck Creek well (USGS-370248090042601)

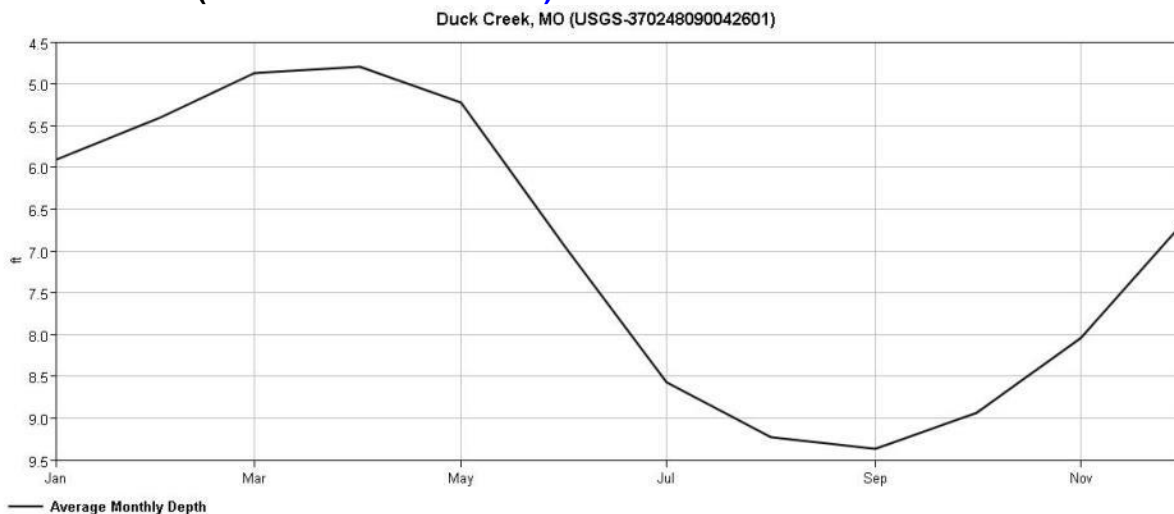


Figure 5.19: Average Monthly Depth to Groundwater (1957-2015) for (USGS-370248090042601), Duck Creek well

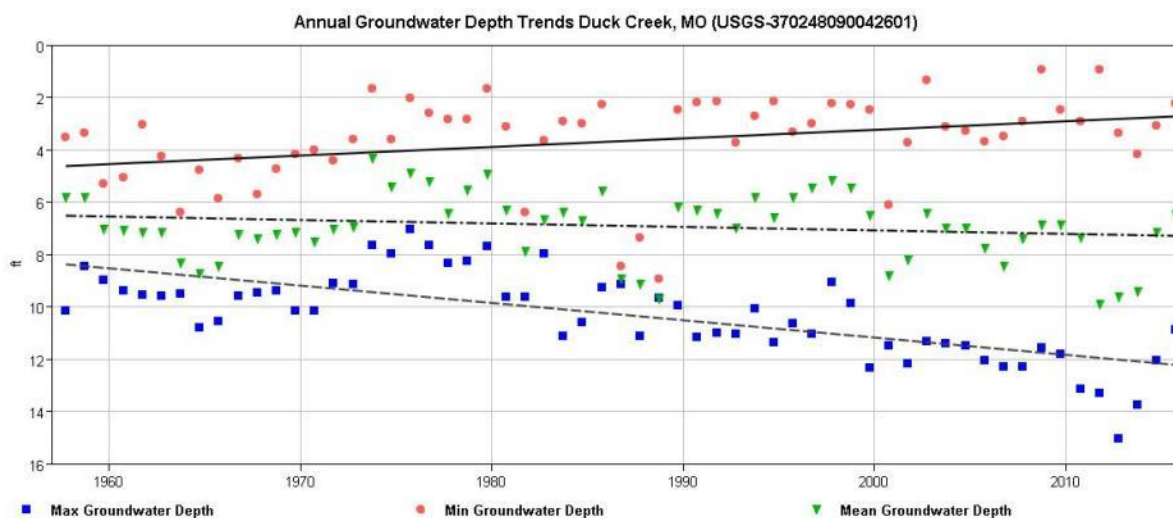


Figure 5.20: Annual mean, minimum, and maximum depth to groundwater (1957-2015) for (USGS-370248090042601), Duck Creek well

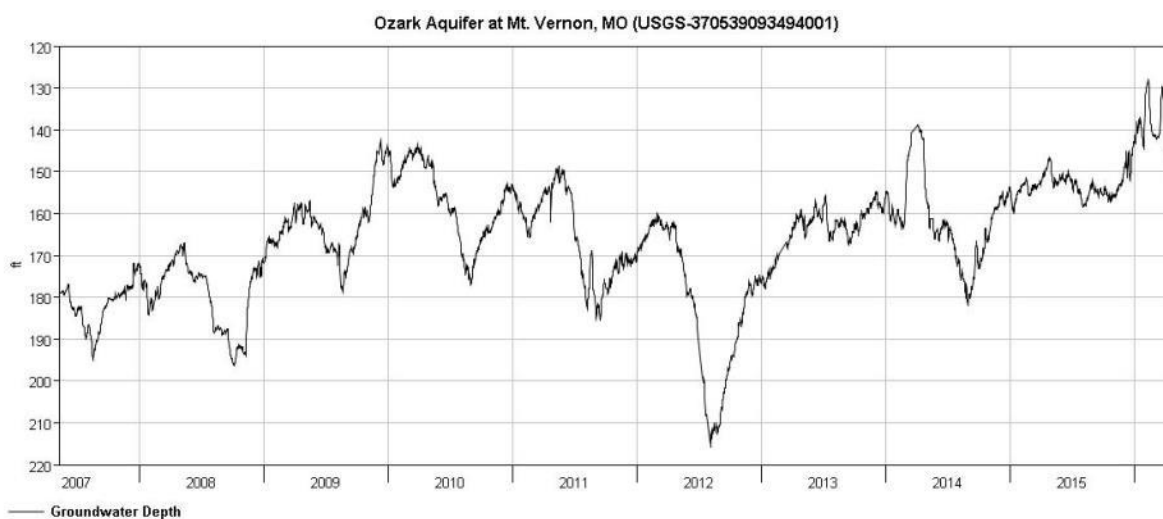


Figure 5.21: Daily average depth to groundwater (2007-2016) for USGS-370539093494001, Mt. Vernon Ozark Aquifer well

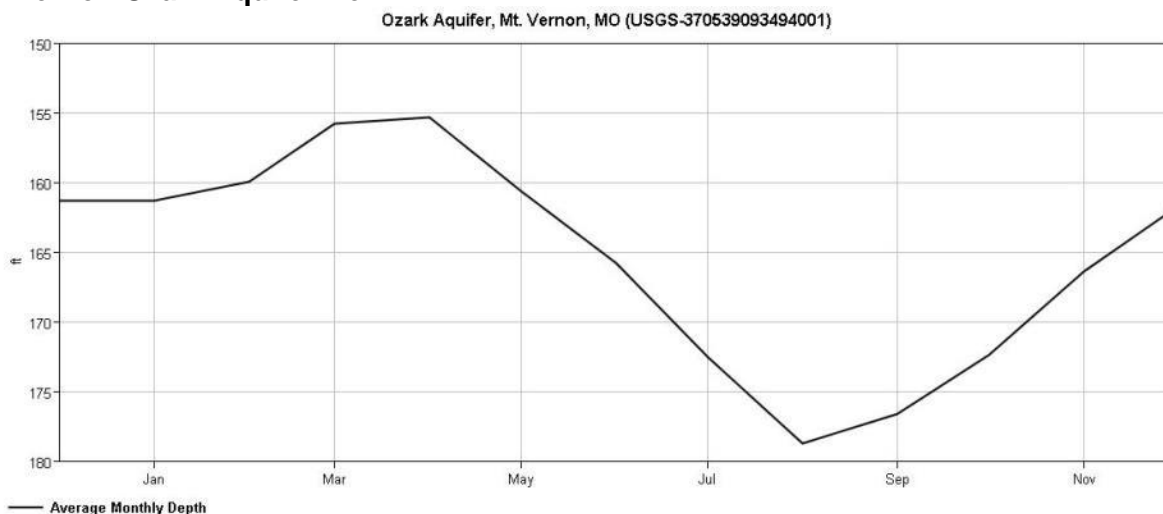


Figure 5.22: Average monthly depth to groundwater (2007-2016) for USGS-370539093494001, Mt. Vernon, Ozark Aquifer well

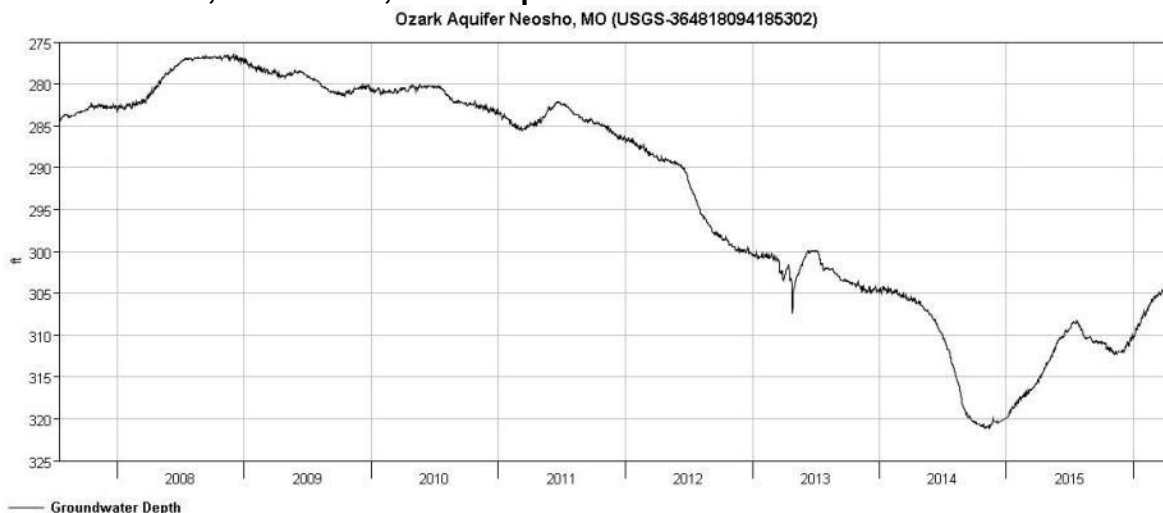


Figure 5.23: Daily average depth to groundwater (2005-2016) for (USGS-364818094185302), Neosho Ozark Aquifer well

5.4 Water Quality Criteria

The Environmental Protection Agency developed technical guidance manuals and nutrient criteria for the protection of aquatic life in various types of waters specific to different ecoregions. Those developed for rivers/streams and lakes/reservoirs for ecoregions are summarized below (USEPA 2000,2001; Table 5.2, 5.3). These criteria are relevant to individual streams and lakes within MNWR, PKNWR, and OCNWR's Regions of Hydrologic Influence (RHI), but do not necessarily apply to Refuge wetland units. In Missouri, the application of numeric criteria to wetlands depends on specific wildlife and vegetation requirements.

Additional information related to the application of federal water quality standards and regulations to wetlands is provided by the EPA's Water Quality Standards Handbook (<http://water.epa.gov/lawsregs/guidance/wetlands/quality.cfm>). Procedures outlined in this handbook are used when specific criteria for wetlands are developed.

Parameter	Rivers and Streams	Lakes and Reservoirs*
TP (ug/L)	128	-
TN (mg/L)	0.76	-
Chl <i>a</i> (ug/L)	2.10 (Spectrophotometric)	-
Turb (FTU)	17.5	-
Secchi (m)	-	-

Table 5.2: Nutrient criteria for rivers/streams and lakes/reservoirs established for ecoregion X: Texas-Louisiana Coastal and Mississippi Alluvial Plains (EPA 2001) (Lakes and Reservoirs still under development)

Parameter	Rivers and Streams	Lakes and Reservoirs
TP (ug/L)	10	8
TN (mg/L)	0.31	0.46
Chl <i>a</i> (ug/L)	1.61 (Spectrophotometric)	2.79
Turb (NTU)	2.3	-
Secchi (m)	-	2.86

Table 5.3: Nutrient criteria for rivers/streams and lakes/reservoirs established for ecoregion XI: Central and Eastern Forested Uplands (EPA 2000)

The EPA has compiled national recommended water quality criteria for roughly 150 pollutants (<http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm>) to provide guidance in developing state-specific standards. The development of state and federal water quality standards requires consideration for the existing and potential uses of water bodies. Different uses often require different levels of protection for specific pollutants. Water bodies may have several different uses associated with them, such as aquatic life and recreation, in which case criteria for each pollutant are determined based on the most vulnerable designated use (<http://water.epa.gov/drink/contaminants/#List>).

Specific state water quality standards and the associated measurement methodology can be found in Chapter 7 of the Missouri Code of State Regulations (10 CSR 20-7.010 - 10 CSR 20-7.050, <http://water.epa.gov/scitech/swguidance/standards/upload/mowqs.pdf>). MNWR pools are listed as lake assessment units, and the designated uses include livestock and wildlife

watering, protection of warm water aquatic life and human health-fish consumption, whole body contact recreation, and secondary body contact recreation (State of Missouri 10 CSR 20-7). Impairment listings for assessed waterbodies relevant to the Refuges are discussed in Section 5.5.

5.5 Surface Water Quality

Mingo National Wildlife Refuge

Surface water quality information for Mingo NWR is somewhat lacking and the most available data is related to the issue of mercury deposition (see Contaminant Assessment Protocol section). Water samples were collected at a handful of sites in Mingo NWR eight to nine years ago. Various metals and other chemicals were detected in the samples, including silver, nickel, lead, arsenic, and selenium samples. There is a water quality sampling site located outside of the Refuge downstream from the Wappapello Dam on the St. Francis River (Figure 5.24). Fifty-two samples were collected from this site from 1987 to present by the Missouri DNR including dissolved nutrients, dissolved oxygen, pH, and conductivity. The water quality at this location does is not representative of the Refuge, so the data was not analyzed for this report.

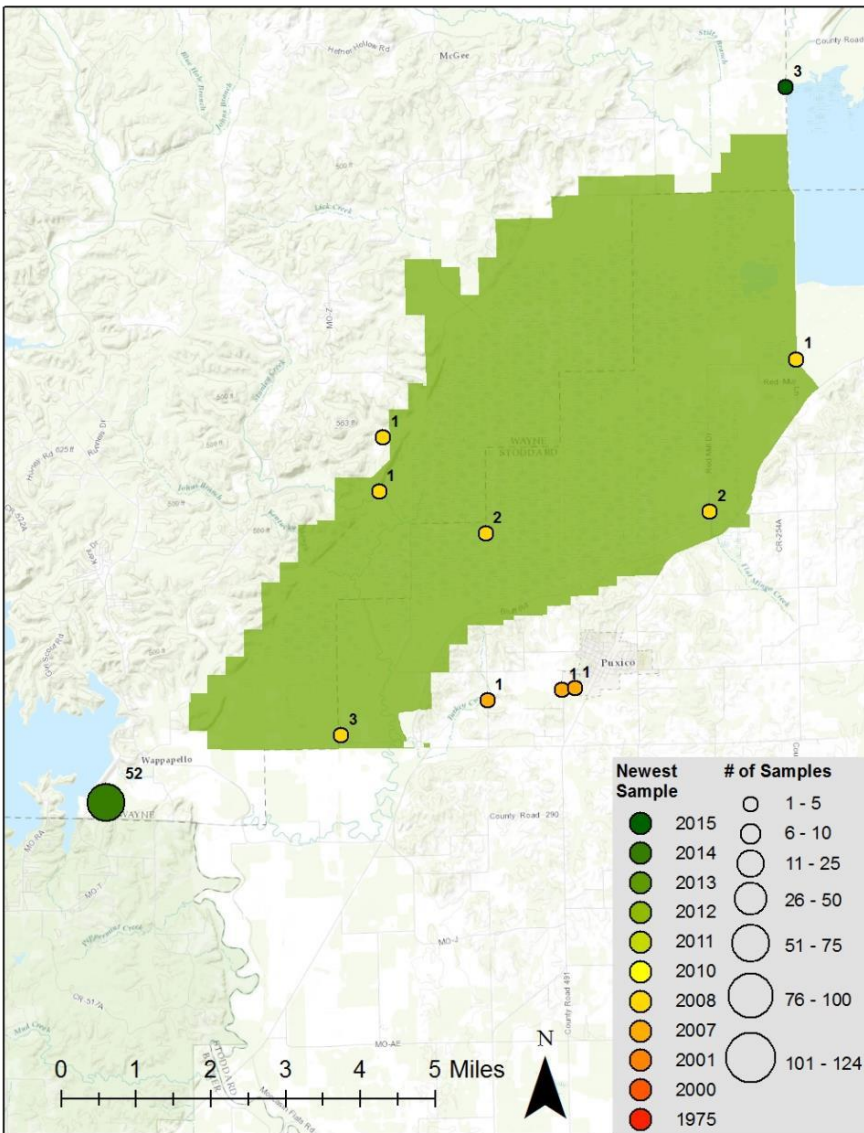


Figure 5.24: Map of water

quality data availability from MO DNR in the Mingo NWR area.

Pilot Knob National Wildlife Refuge

Water quality data near Pilot Knob NWR is very sparse. There are only a handful of samples from nearby Knob Creek that are from the years 1975 and 2000 (Figure 5.25). Due to the limited amount of data at this site, and the fact that Knob Creek does not flow through the Refuge, water quality data was not assessed for PKNWR in this report.

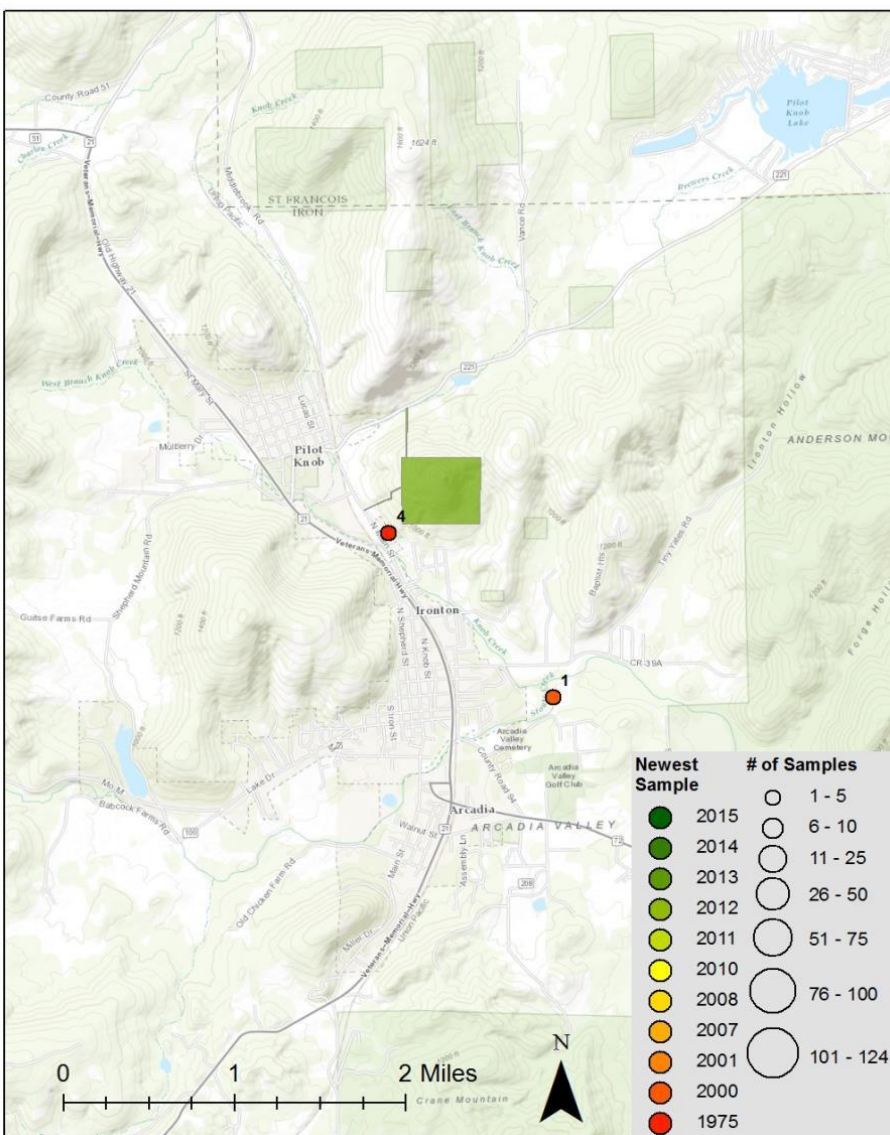


Figure 5.25: Map of water quality data availability from MO DNR in the Pilot Knob NWR area.

Ozark Cavefish National Wildlife Refuge

There is fairly extensive water quality data in close proximity to the Ozark Cavefish NWR- Turnback Cave Unit. The most pertinent data was collected on Turnback Creek just upstream of the Refuge at the adjoining Paris Springs Conservation Area (Figure 5.26). This sampling site was monitored by the Missouri DNR (MO DNR), the U.S. EPA, and the Lawrence County Health Department (LCHD). The MO DNR and EPA monitored for dissolved nutrients and other water quality parameters, while the Health Department monitored for E. Coli counts. In total there are 50 samples, but 26 of them solely record E. Coli values. The period of record for this site goes from 2005 to 2014.

The data from these sampling efforts are summarized in Table 5.3 When comparing these values to the U.S. EPA water quality criteria for Ecoregion XI, it can be seen that while Total Nitrogen (TN) is about 6.5 times higher than the EPA standard, the Total Phosphorus (TP) is only 1.6 times higher. Chlorophyll-a concentrations are right around the criteria provided by the

EPA, but the average turbidity is actually slightly higher than the EPA standard. This seems to indicate that based on the set of samples available and EPA criteria, Turnback Creek is impaired, due to dissolved nutrient levels and turbidity. The water quality in Turnback Creek directly affects the Refuge as it passes through the middle of it and may in fact inundate Turnback Cave during times of flooding. Additionally, Turnback Creek is State-Listed as a coldwater fishery in the vicinity of OCNWR (Missouri 10 CSR 20-7).

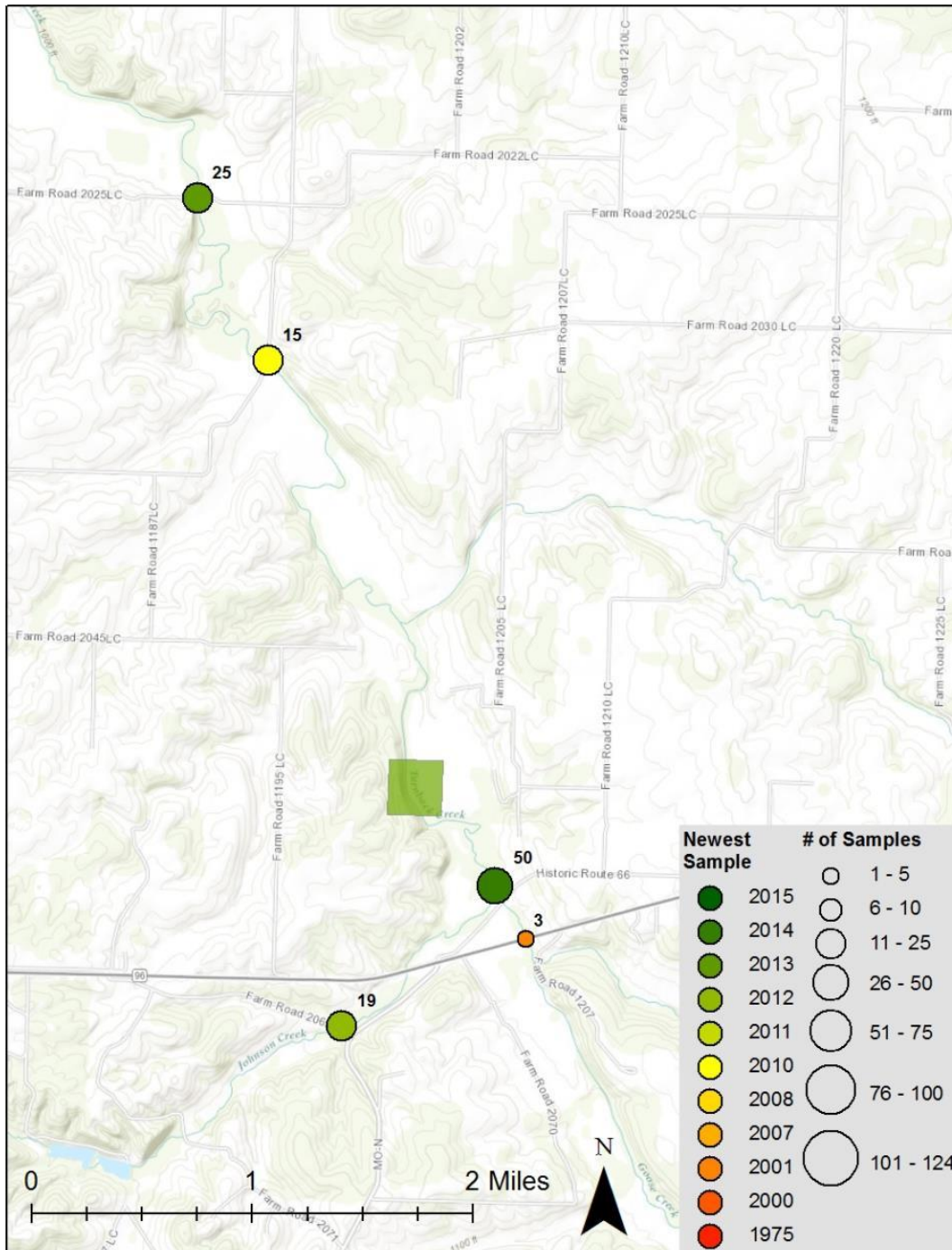


Figure 5.26: Map of water quality data availability from MO DNR in the Ozark Cavefish NWR- Turnback Cave Unit area.

Turnback Creek at Paris Springs Conservation Area							
		Sampling Record		2005-2014			
		Total Sample		50			
Parameters	Chl. A (µg/L)	T.N. (mg/L)	T.P. (µg/L)	D.O. (mg/L)	Turbidity (NTU)	Sp. Cond. (µs/cm)	E. Coli (cells/100ml)
Mean	1.63	2.03	16.93	8.80	4.56	359.18	201.41
Median	1.35	2.12	17.3	8.93	3.40	365.00	137.2
S.D.	1.54	0.49	15.77	2.35	3.01	52.04	145.288
Samples	14	22	21	15	14	22	26

Table 5.4: Statistics of selected water quality parameters for Turnback Creek at Paris Springs Conservation Area

The Hearrell Spring Unit of Ozark Cavefish NWR is fairly close to several water quality sampling sites. However, these sites do not likely affect the Refuge directly because the spring's recharge zone lies to the south and east of the city of Neosho.

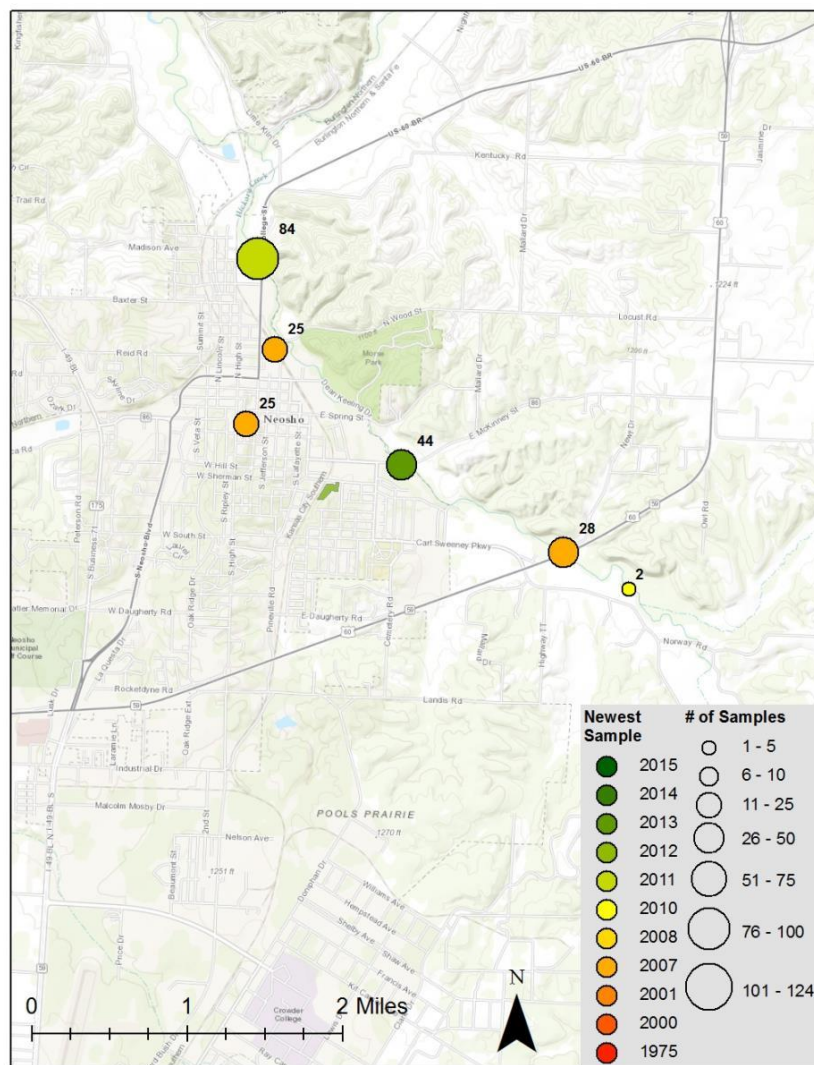


Figure 5.27: Map of water quality data availability from MO DNR in the Ozark Cavefish NWR- Hearrell Spring Unit area.

303(d) assessments

Section 303(d) of the Clean Water Act requires that each state identify water bodies where water quality standards are not met based on designated usage. Section 303(d) data from the State of Missouri was utilized to identify any impaired streams, rivers, or lakes on or in close proximity to the Refuges.

Mingo NWR

As of the 2016 Missouri 303(d) list, there are currently no impairments for waters within Mingo NWR or within the Mingo Swamp Basin. However, the lack of impairments may be associated with the lack of assessment of Mingo's smaller tributaries. The only nearby impairment is for a seven mile stretch of the Castor River located about 5.5 miles from Refuge boundaries (Figure 5.28). This impairment is for *Escherichia coli* caused by rural nonpoint sources and affects Whole Body Contact designated use. Aquatic life and Secondary Contact Recreation are listed as unaffected. The Castor River only directly affects Mingo NWR during times of flooding.

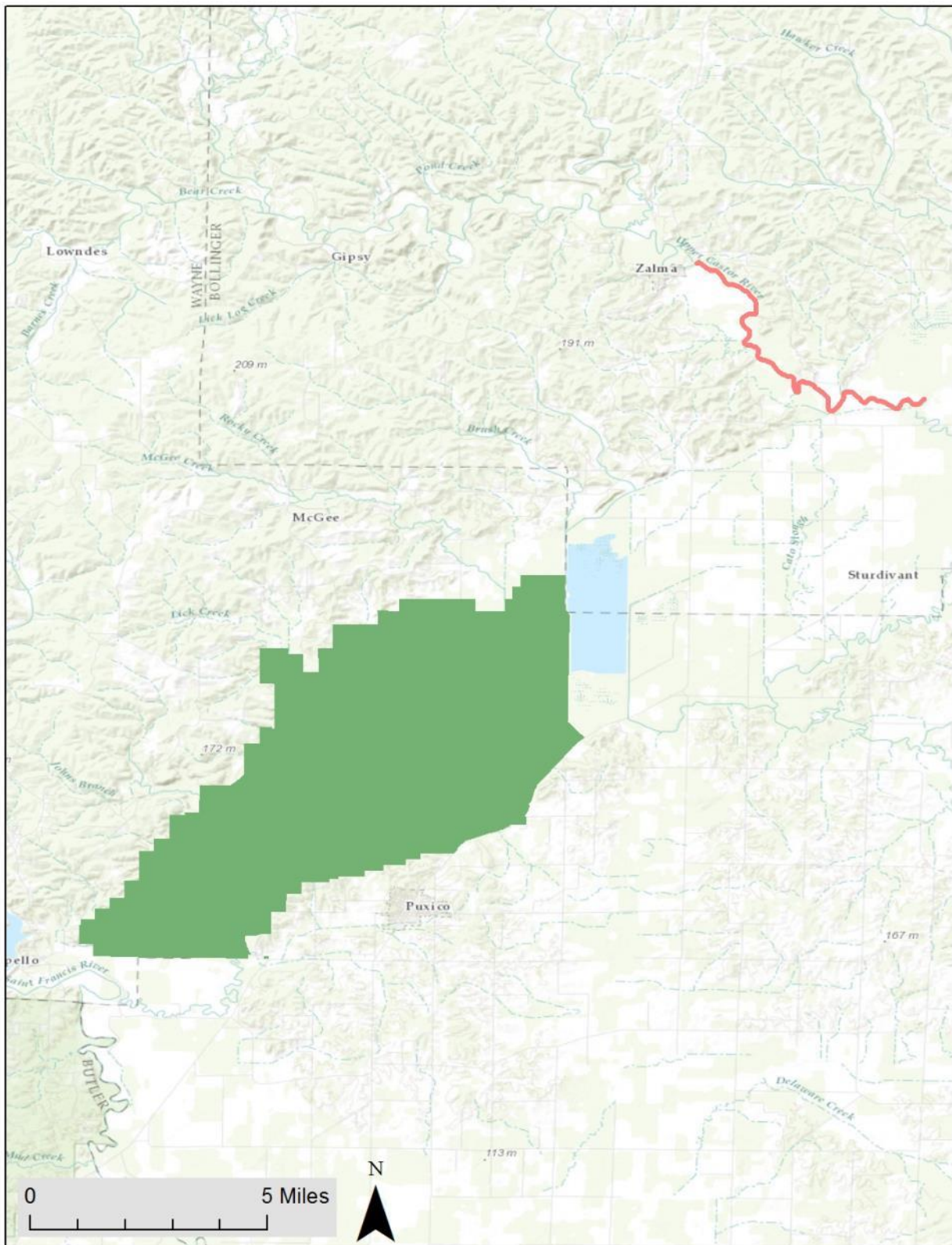


Figure 5.28: Map of impaired waters near MNWR.

Pilot Knob NWR

There are no 303(d) impaired waters near Pilot Knob NWR.

Ozark Cavefish NWR

Turnback Cave Unit has an impaired section of river passing through the Refuge boundaries. There are 19.9 miles of Turnback Creek that are listed by the State of Missouri as impaired due to *E. coli* from rural nonpoint sources and affects Whole Body Contact designated use. Aquatic life and Secondary Contact Recreation are listed as unaffected. Additionally, there are three miles of a tributary to Goose Creek that are impaired due to *Escherichia coli*. Goose Creek lies a short distance upstream of Turnback Cave. For average *E. coli* concentrations in Turnback Creek see Table 5.3.

The Hearrell Spring Unit does not have any impaired waters directly within its boundaries. However, there are 4.9 miles of Hickory Creek nearby that are impaired due to *Escherichia coli* from rural nonpoint sources. Hickory Creek does not directly affect the Refuge (see Section 3.1 for more details).

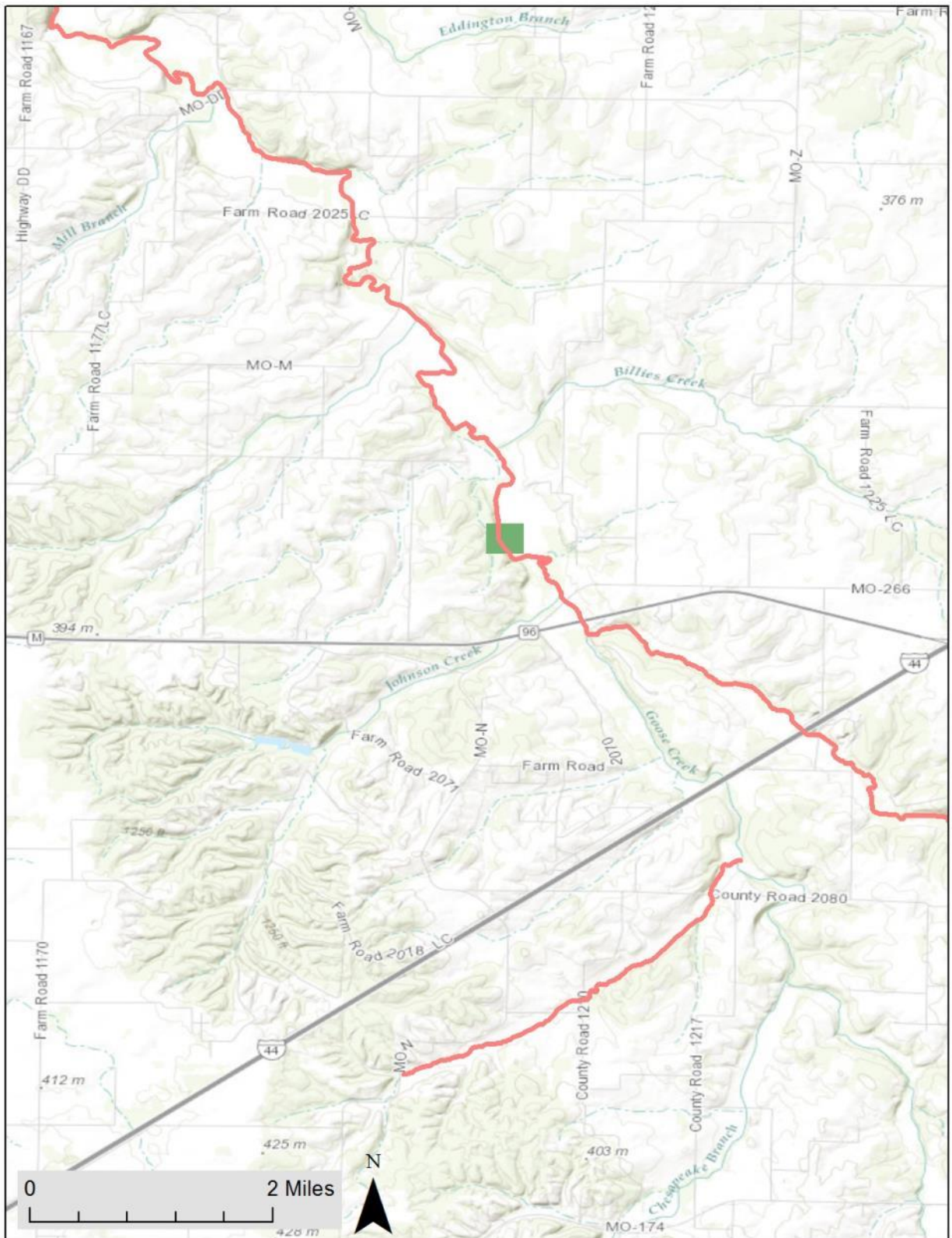


Figure 5.29: Map of impaired water near OCNWR- Turnback Cave unit.

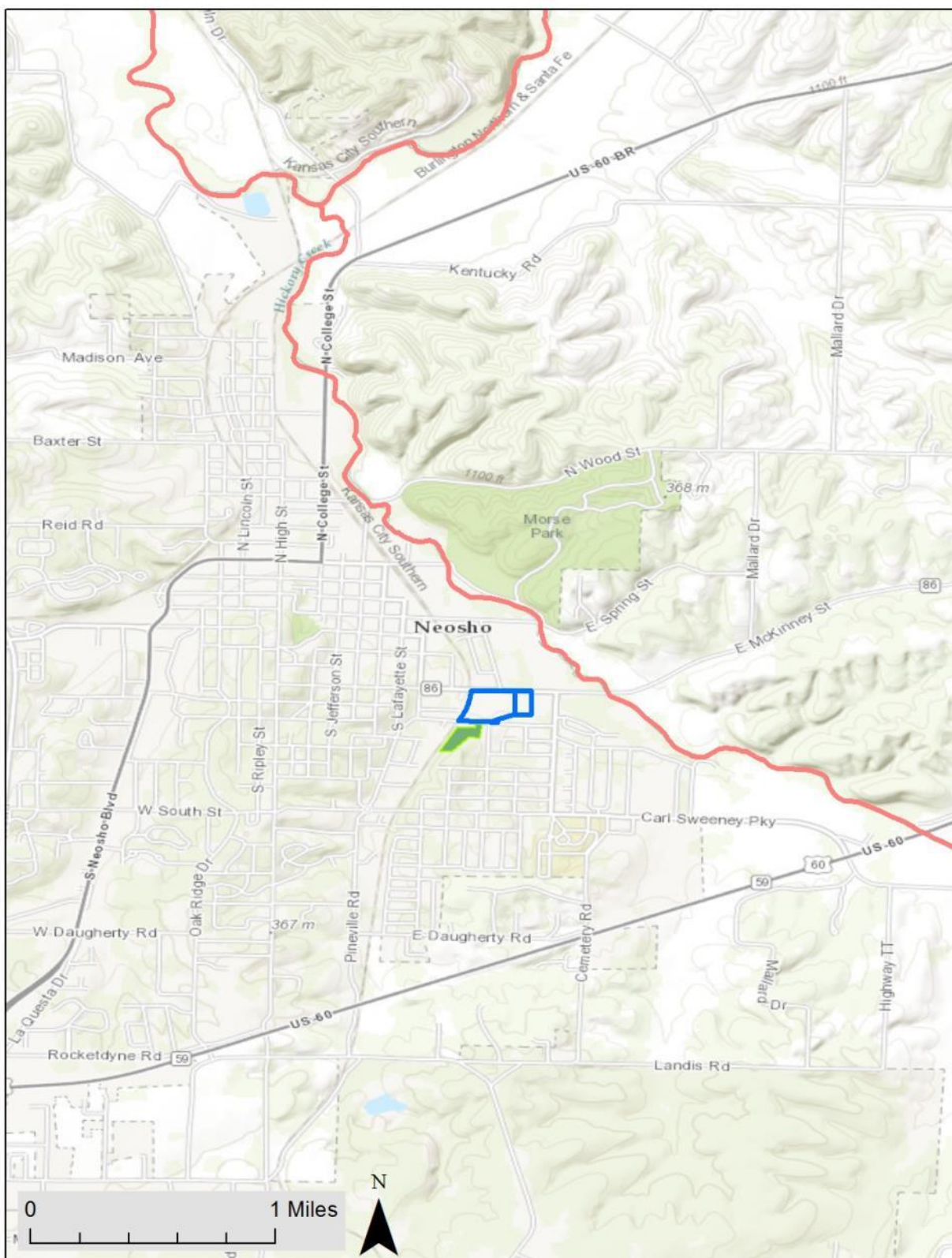


Figure 5.30: Map of impaired waters near OCNWR- Hearrell Spring Unit

Contaminant Assessment Process (CAP)

Mingo NWR

Joshua Hundley, along with Dave Mosby and John Weber all from the Columbia Ecological Services Field Office, MO, completed the most recent CAP for MNWR in 2013. This included information on particular contaminants of concern to fish and wildlife resources on the Refuge and areas of the Refuge of specific interest with regard to these contaminants. Many findings included in the CAP came from published studies done at the Refuge. These studies are cited in the CAP. The major relevant points within the CAP (Hundley 2013) were:

- An On-Refuge Contaminant Investigation at Mingo indicated that the Refuge is impacted by mercury deposition, primarily from nearby coal-burning power plants. Mercury is a concern because it can concentrate in the tissues of aquatic and terrestrial organisms, particularly in higher trophic level fish and birds of prey, such as the bald eagle. In addition to mercury contamination, previous data collected at the Refuge showed elevated levels of selenium in fish tissues.
- There are wastewater discharges as well as some non-point source drainages in neighboring watersheds that are likely introducing contaminants to the Refuge. Water transported contaminants from these sources can include hormonally active agents, nutrients, as well as agricultural and silvicultural chemicals. There are a wide variety of organisms, including the federally listed Indiana bat and numerous waterfowl that utilize MNWR habitat that could be negatively impacted by contaminants in the environment.
- There are many local and regional regulated air emissions in the surrounding area of the Refuge. Chemicals from these emissions, including dioxins, heavy metals, gases, and particulates could be transported to the Refuge.
- Many tentative Potentially Contaminated Areas (PCAs) were identified for the Refuge. These were associated with open-air depositional and incoming surface water flow locations. One PCA that is a known source of contamination is the Mingo Job Corps site. This facility formally contained underground petroleum storage tanks adjacent to the Refuge. When the tanks were removed from the site contamination from leakage was discovered. Soil and groundwater in the area have high concentrations of petroleum constituents. Usually groundwater flows away from the Refuge but during high stream flow events groundwater flow can reverse heading back toward the Refuge.
- Some areas of the Refuge are subject to potential spills and this can pose a threat to habitat and organisms residing in those areas. State Highway 51 which traverses the southeast side of the Refuge is a particular threat because of its use as a transportation corridor. A few other possible spill areas identified include the Mingo Job Corps site, national forest service lands and off refuge cropland, where practices may have accidental releases of fuels or pesticides. Depending on the area of a spill, contents can spread through waterways and on land.

Pilot Knob NWR

There is no CAP currently available for Pilot Knob NWR.

Ozark Cavefish NWR

Ozark Cavefish NWR does not have currently have a CAP completed. Although there is not a CAP for this Refuge, a study completed in 2012 looked at the potential impacts of mining contaminants on stygobites (small creatures living in groundwater systems) including the federally-listed threatened Ozark Cavefish, and found that these organisms were unlikely to be present in sites sampled inside designated mining-impacted areas (Novinger et al., 2012). These mining areas were found to have high concentrations of metals and sulfate, a lack of nutrients (low nitrates and nitrites), and low dissolved oxygen levels. The alterations of these parameters are believed to have a deleterious effect on the Cavefish populations. In addition to the possible impacts brought up by this study, one of the main threats foreseen at OCNWR is the proximity of the Refuge to Interstate I-40 and the potential for spills due to the transportation corridor (See Figure 3.8).

6. Water Law

Listed below is a summary of Missouri water law from the Department of Interior Solicitor's Office. Potential implications would be that Mingo NWR would not be able to hold back as much water if it was needed for drinking by humans or livestock. If the Refuge were to exceed 100,000 gallons per day of groundwater use, they would need to register with the State of Missouri. In addition, if they were construct a dam across any of its streams or ditches, they would need to include a fish ladder.

Missouri's judicially defined reasonable-use rule provides that riparian owners have the "right to the flow of the stream in its natural course and natural condition in respect to both volume and purity, except as affected by reasonable use by other proprietors."¹ Landowners' riparian rights include "the limited right to use the water to irrigate [their] land," so long as the "natural wants" of other riparian owners are met.² These "natural wants," consisting of "drinking water for family and livestock," take priority over other water uses.³ Courts determine what constitutes reasonable use on a case-by-case basis, looking at, among other things, "the volume of water in the stream, the seasons and climatic conditions, and the needs of other riparian proprietors."⁴

The state of Missouri does not have a sophisticated water permitting system like some of the other Region 3 states. However, it has taken some measures to, at a minimum, inventory and plan for long-term water resource use. The state tasked the Missouri Department of Natural Resources (DNR) to develop a State Water Resources Plan in order to assess the existing and future needs of surface and ground water for "drinking water supplies, agriculture, industry, recreation, environmental protection and related needs."⁵ As part of the state water resources program, the DNR also has the duty of creating a plan for water resource emergencies.⁶ The water inventory examines: (1) existing surface and groundwater uses, (2) quantities available for future uses, and (3) water extraction and use patterns, including both regulated and unregulated users.⁷ Based on the collected data, DNR can then make recommendations annually to the general assembly about potential statutory revisions that should be made related to the state's water laws.⁸

DNR uses a registration program to facilitate its water resource inventory. The program requires "major water users," or those users with a "water source and equipment necessary" to withdraw or divert at least 100,000 gallons-per-day from any surface or ground water source,⁹ to register with the Missouri Division of Geology and Land Survey by providing information regarding the water source, the installation, the purpose used, the time of year withdrawals will be made, and the daily and annual amounts withdrawn.¹⁰

Missouri has implemented a smattering of either permit programs or regulations for other activities on public waters. As an example, the state requires permits for dam construction on public waters,¹¹ which includes a requirement to construct a chute for fish.¹² Failure to construct

¹ *Bollinger v. Henry*, 375 S.W.2d 161, 166 (Mo. 1964).

² *Id.*

³ *Id.*

⁴ *Id.*

⁵ Missouri Rev. Stat. § 640.415.

⁶ Missouri Rev. Stat. §256.440–443.

⁷ Missouri Rev. Stat. § 640.412

⁸ Missouri Rev. Stat. § 640.415.

⁹ Missouri Rev. Stat. § 256.400(4).

¹⁰ Missouri Rev. Stat. § 256.410.

¹¹ Missouri Rev. Stat. § 236.435.

a chute to the statutorily defined parameters constitutes a public nuisance.¹³ Also, the state, through its Well Installation Board, regulates well drilling to a limited extent.¹⁴

At the local level, the state has authorized communities to establish water supply districts, water conservancy districts, drainage districts, and levee districts. Community public water supply districts may determine the scope of the district and have powers delegated by the state, such as eminent domain and taxation, to administer the construction and maintenance of a water supply.¹⁵ Similarly, community members can establish water conservancy districts that focus on protection of a primary water source in their region.¹⁶ These districts have the delegated power to take actions such as imposing fees on irrigation wells.¹⁷ Since excessive water seems to pose more of a threat to Missouri citizens than water shortages, community-administered drainage and levee districts exist to construct projects for the purpose of reclaiming swampland for either sanitary or agricultural reasons, so long as the drainage or levee activities do not negatively impact the public.¹⁸ The state places much emphasis on the role of local communities to control water resources.

¹² Missouri Rev. Stat. § 236.230.

¹³ *Id.*

¹⁴ Missouri Rev. Stat. §§ 256.600–256.660.

¹⁵ Missouri Rev. Stat. §§ 247.010–247.673.

¹⁶ Missouri Rev. Stat. §§ 256.030–256.070.

¹⁷ Missouri Rev. Stat. § 256.655.

¹⁸ Missouri Rev. Stat. § 242.563; *see, also*, Missouri Rev. Stat. §§ 242.010–242.750, 245.010–244.205.

7. Geospatial Data Sources

HUC polygons are available from the EPA as part of the Watershed Boundary Dataset (WBD). These boundaries were delineated in cooperation with the USGS using methodology adapted from Seaber et al. (1987)

The most recent high resolution LiDAR data (1 m cell size) is available in the North American Vertical Datum (NAVD 1988). This lidar was data collected in 2006, and processed by Vince Capeder (USFWS, 2012). It was combined with bathymetry from Mingo NWR staff to create the DEM for Mingo NWR used in this WRIA.

The National Elevation Dataset- USGS. The National Map. 2016. 3DEP Products and Services. <http://nationalmap.gov/elevation.html>

The National Wetland Inventory- USFWS. 1985-1986. National Wetlands Inventory website. U.S. Department of the Interior, USFWS, Washington, D.C. <http://www.fws.gov/wetlands/>

Background aerials are from the U.S. Department of Agriculture National Agriculture Imagery Program.

The National Hydrologic Dataset (NHD) is produced as a cooperative effort by the Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), and other federal and state agencies.

303(d) impaired waters were obtained from the Missouri DNR (2016)

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9. Appendix A: Relevant Water Monitoring Locations

Site Name	ID and Link	Location	Elevation	Notes	Record maintained by:
St. Francis River at Wappapello, MO	USGS-07039500	Latitude 36°55'41.2", Longitude 90°15'55" NAD83	Drainage area: 1,311 square miles; 314.56 feet (NAVD88)	Daily discharge/peak streamflow data.	USGS Missouri Water Science Center and USACE St. Louis District
Castor River at Greenbriar, MO	USGS-06902000	Latitude 39°38'24.1", Longitude 93°16'25.3" NAD83	Drainage area: 6,880 square miles; 631.18 feet (NGVD29)	Daily discharge/peak streamflow data.	USGS Missouri Water Science Center and USACE Kansas City District
Turnback Creek above Greenfield, MO	USGS-06918460	Latitude 37°24'08.5", Longitude 93°48'07.3" NAD83	Drainage area: 252 square miles; 870.49 feet (NGVD29)	Daily discharge/peak streamflow data.	USGS Missouri Water Science Center and USACE Kansas City District
Hickory Creek at Neosho, MO	USGS-07186900	Latitude 36°51'54"N, longitude 94°21'13"W NAD83	1,021 feet (NAVD88)	Daily discharge/peak streamflow data.	USGS Missouri Water Science Center and URS Corporation
Monopoly Marsh near Puxico, MO	USFWS-365718090132500	Latitude 36°59'45", Longitude 90°11'16" NAD83		Daily stage data	USFWS Region 3
Ditch 2 Near McGee, MO	USFWS-370230090074600	Latitude 37°02'30", Longitude 90°07'46" NAD83		Daily average streamflow data, requires further data analysis	USFWS Region 3
Ditch 10 Breach near Puxico, MO	USFWS-365718090132500	Latitude 36°57'18", Longitude 90°13'25" NAD83		Daily average streamflow data, requires further data analysis	USFWS Region 3
Mingo River near Puxico, MO	USFWS-365709090123600	Latitude 36°57'9", Longitude 90°12'36" NAD83		Daily average streamflow data, requires further data analysis	USFWS Region 3
Ditch 1 near Puxico, MO	USFWS-370031090063701	Latitude 37°3'47", Longitude 90°6'37" NAD83		Daily average streamflow data, requires further data analysis	USFWS Region 3
Lick Creek near McGee, MO	USFWS-370210090121700	Latitude 37°2'10", Longitude 90°12'17" NAD83		Daily average streamflow data, requires further data analysis	USFWS Region 3
Mingo Ditch near Wappapello,	USFWS-365611090132600	Latitude 36°56'13", Longitude 90°13'24" NAD83		Daily average streamflow data, requires further data analysis	USFWS Region 3

MO					
Duck Creek, MO	USGS-370248090042601	Latitude 37°02'45.5", Longitude 90°04'29.0" NAD83	344 (NGVD29)	Daily groundwater level measurements, 1956-2016	USGS Missouri Water Science Center and Missouri DNR
Ozark Aquifer at Mt. Vernon, MO	USGS-370539093494001	Latitude 37°05'39.2", Longitude 93°49'40.2" NAD83	1,215 (NGVD29)	Daily groundwater level measurements 2007-2016, Daily Precipitation (2013-2016)	USGS Missouri Water Science Center and Missouri DNR
Ozark Aquifer at Neosho, MO	USGS-364818094185302	Latitude 36°48'17.7", Longitude 94°18'53.1" NAD83	1,265 (NGVD29)	Daily groundwater level measurements 2007-2016	USGS Missouri Water Science Center and Missouri DNR

Table 9.1: Water monitoring stations particularly relevant to Mingo, Pilot Knob, and Ozark Cavefish management

10. Appendix B: USHCN Figures

Mingo National Wildlife Refuge

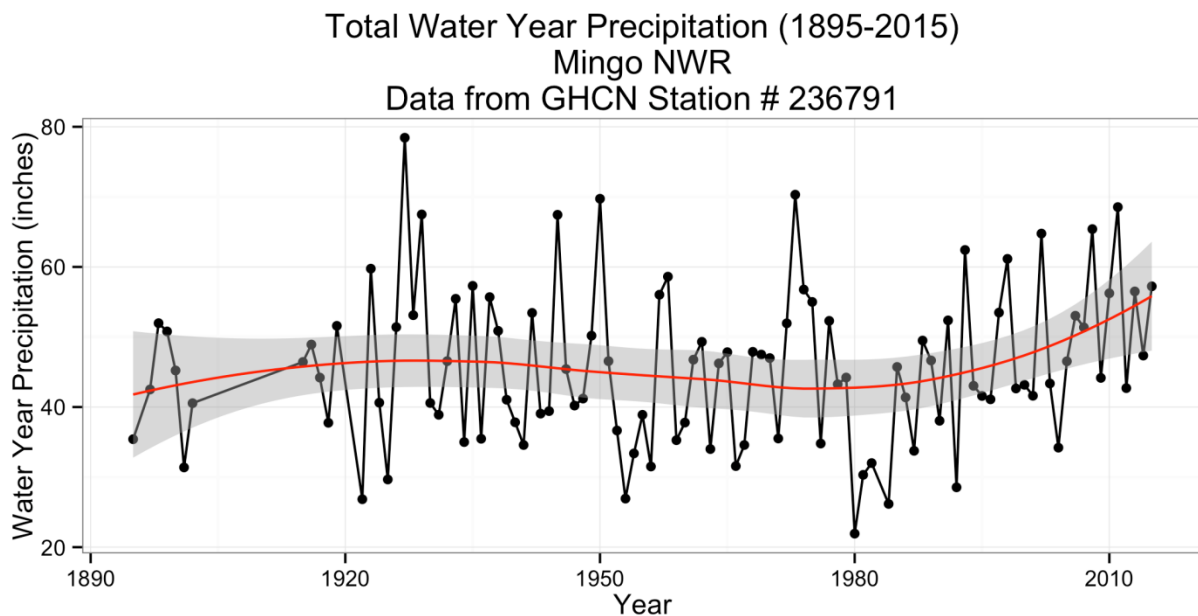


Figure 10.1: Water Year Total Precipitation (1895-2015), Station No. 236791, Poplar Bluff, MO

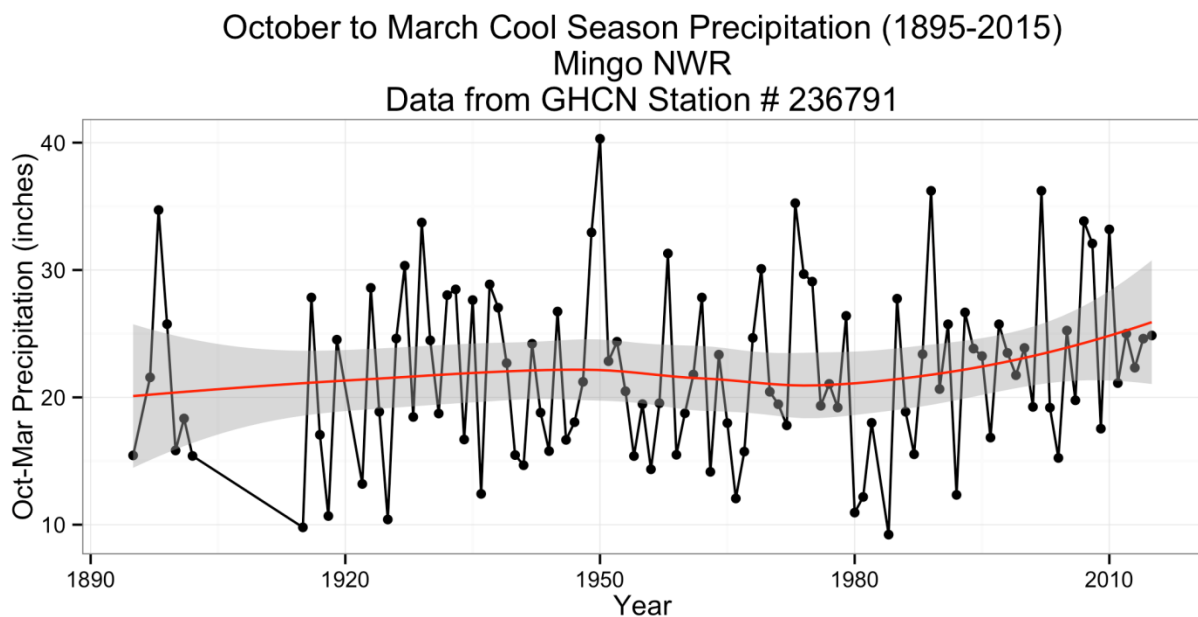


Figure 10.2: Average cool season (Oct-Mar) precipitation (1895-2015), Station No. 236791, Poplar Bluff, MO

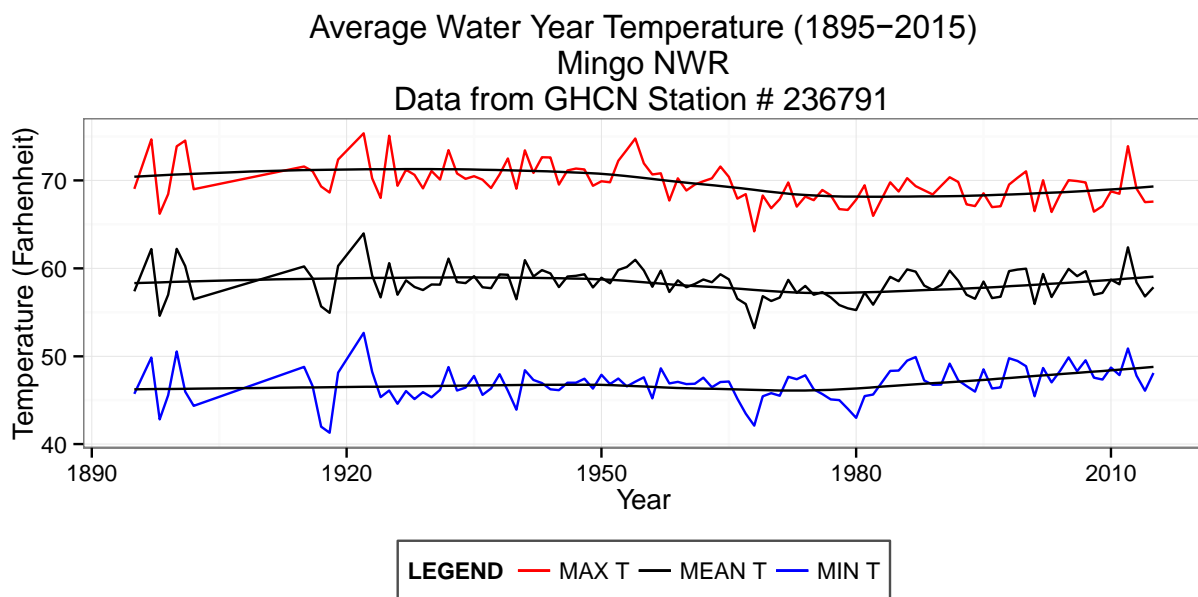


Figure 10.3: Water year average trends in maximum, minimum, and mean temperatures (1895-2015), Station No. 236791, Poplar Bluff, MO

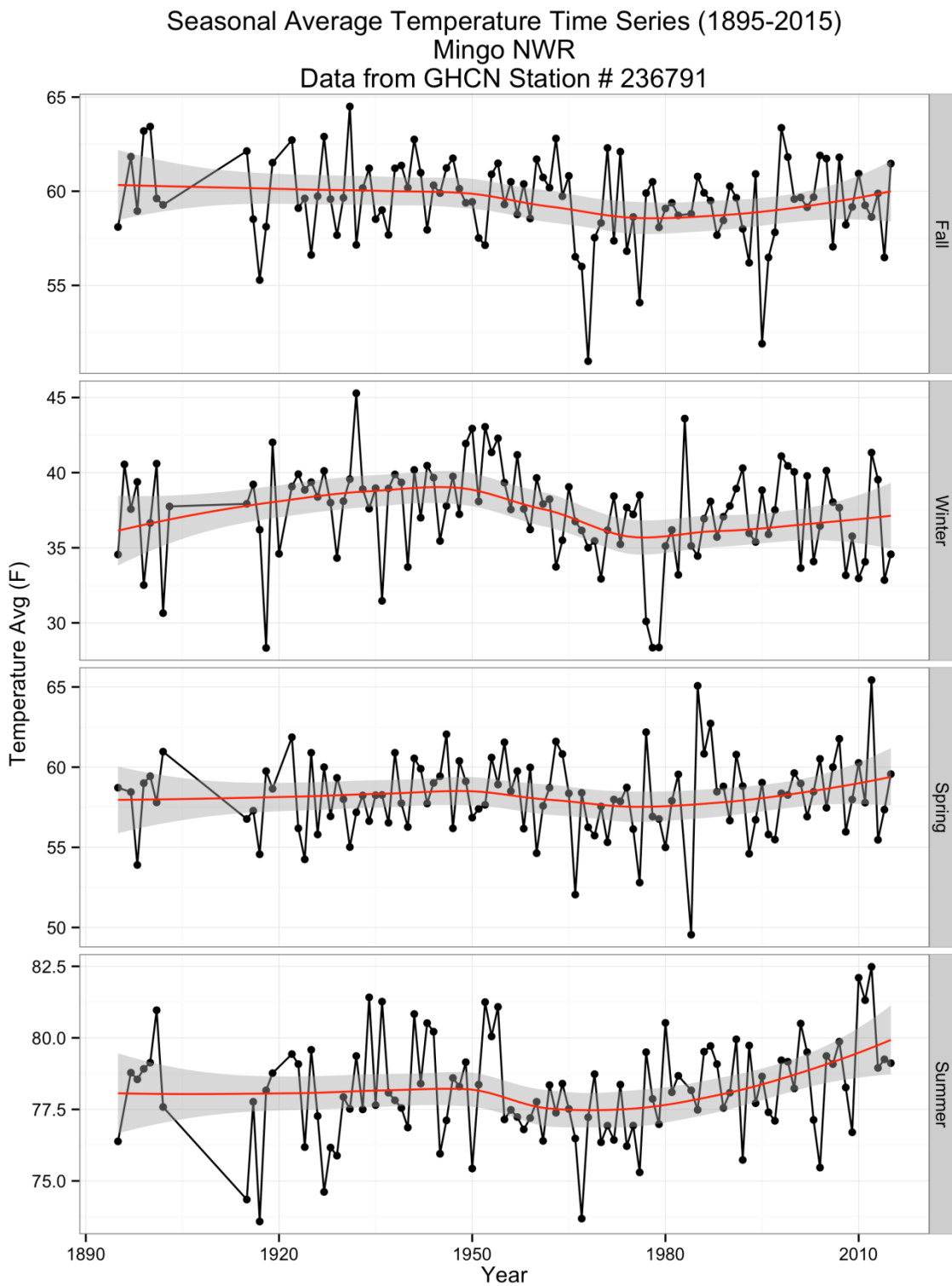


Figure 10.4. Average seasonal temperatures (1895-2015) , Station No. 236791, Poplar Bluff, MO

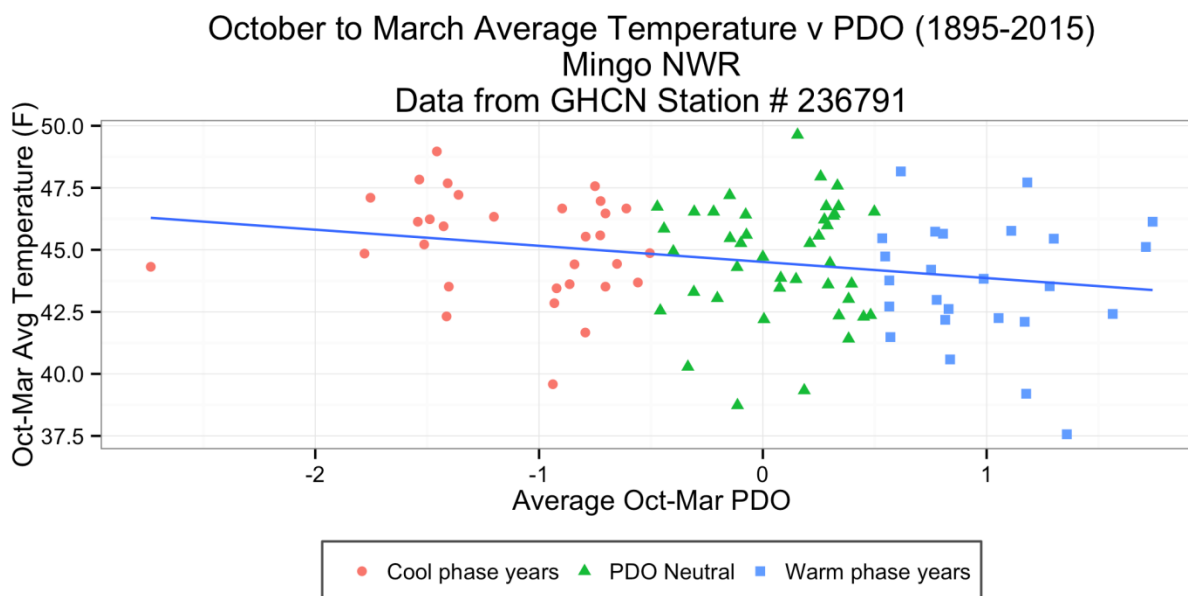


Figure 10.5: Average cool season temperature versus Pacific Decadal Oscillation phase (1895-2015), Station No. 236791, Poplar Bluff, MO

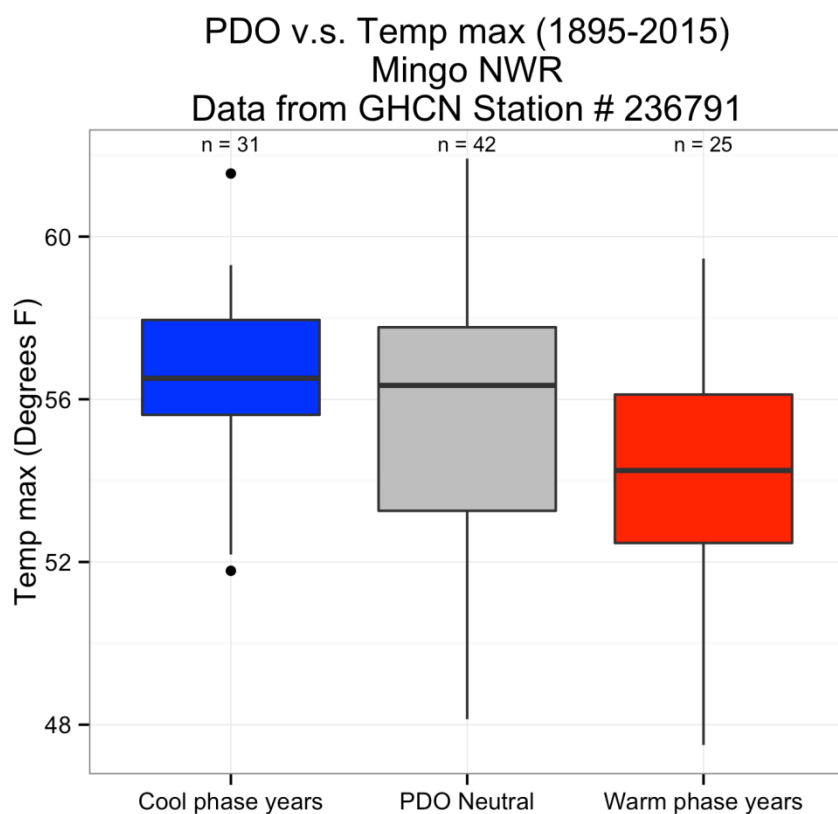


Figure 10.6: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1895-2015), Station No. 236791, Poplar Bluff, MO

Pilot Knob National Wildlife Refuge

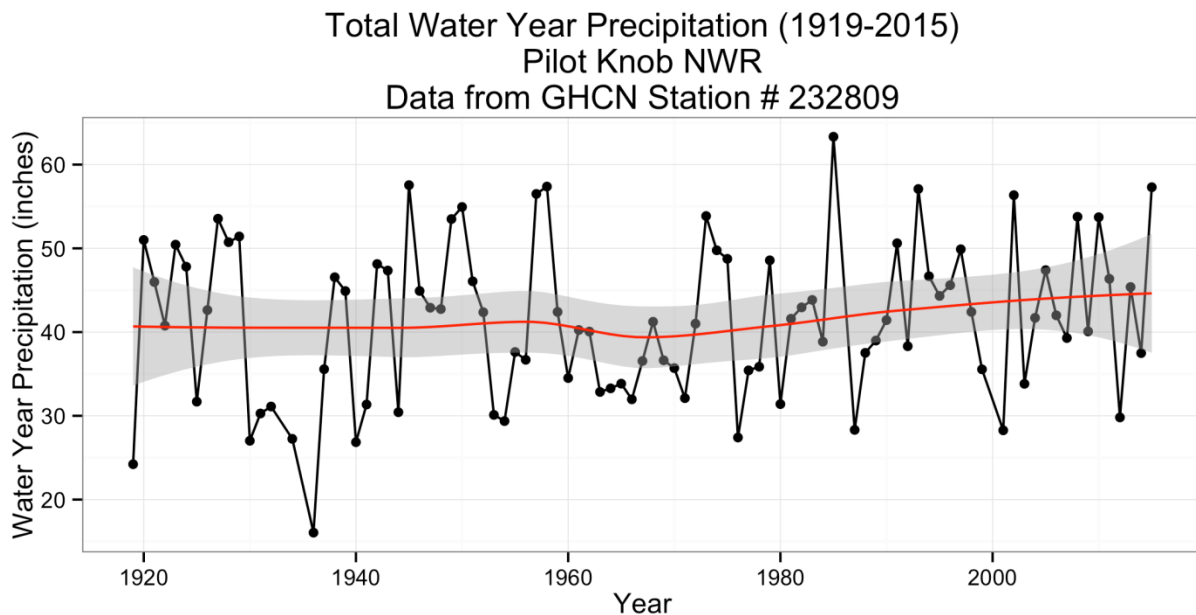


Figure 10.7: Water Year Total Precipitation (1919-2015), Station No. 232809, Farmington, MO

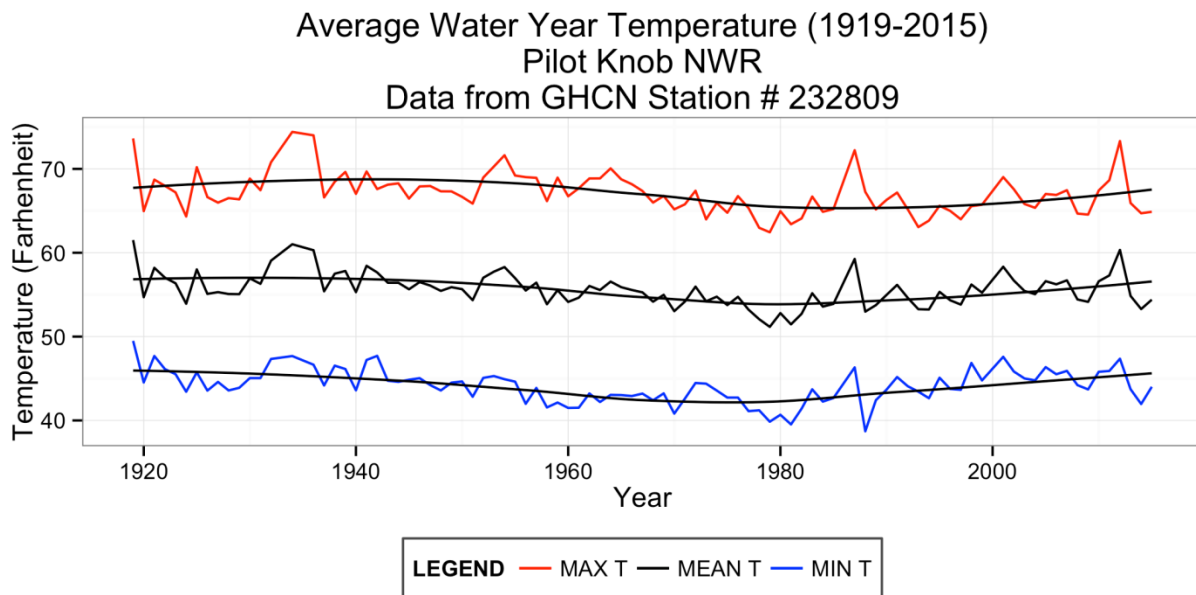


Figure 10.8: Water year average trends in maximum, minimum, and mean temperatures (1919-2015), Station No. 232809, Farmington, MO

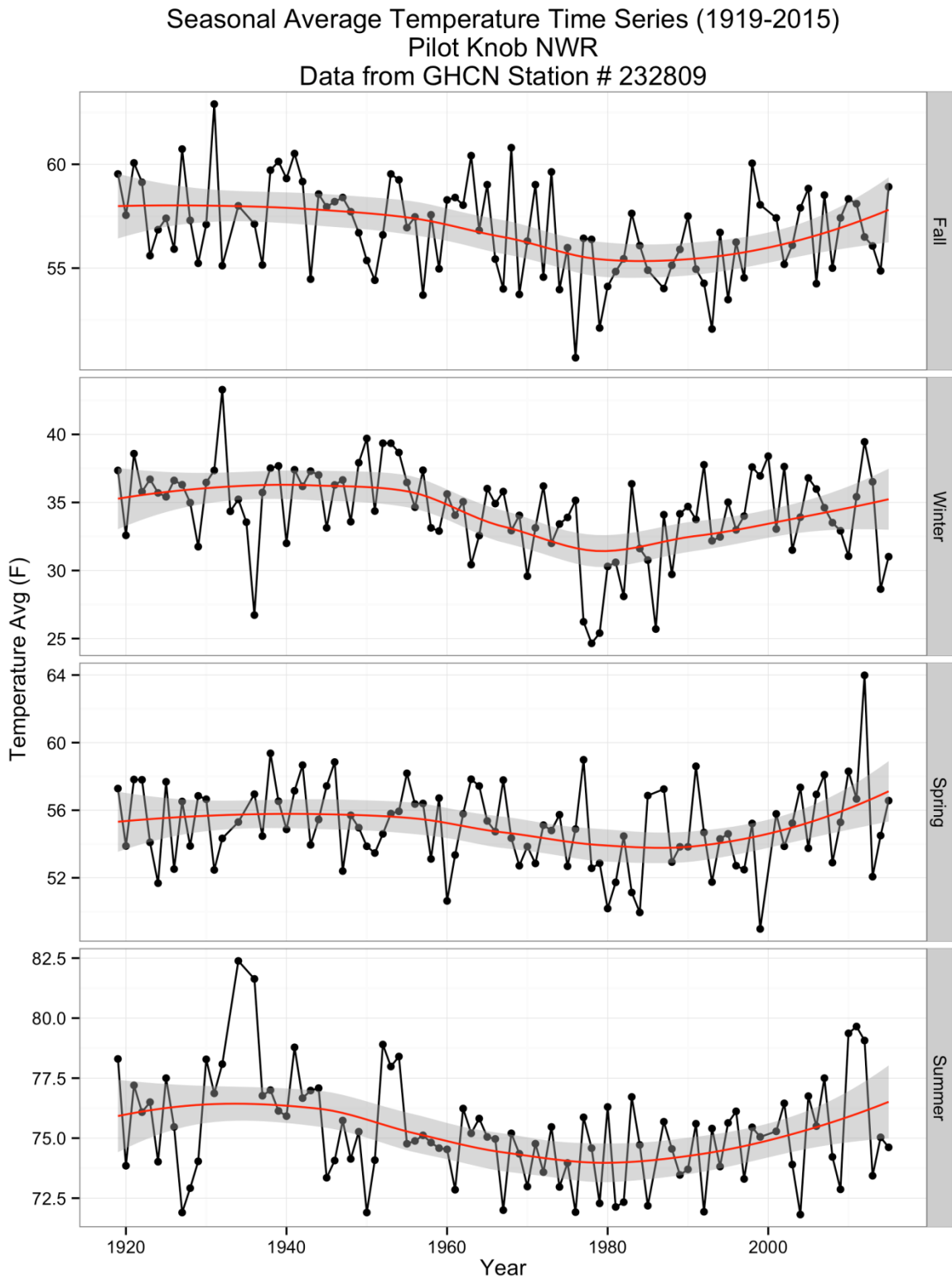


Figure 10.9: Average seasonal temperatures (1919-2015) , Station No. 232809, Farmington, MO

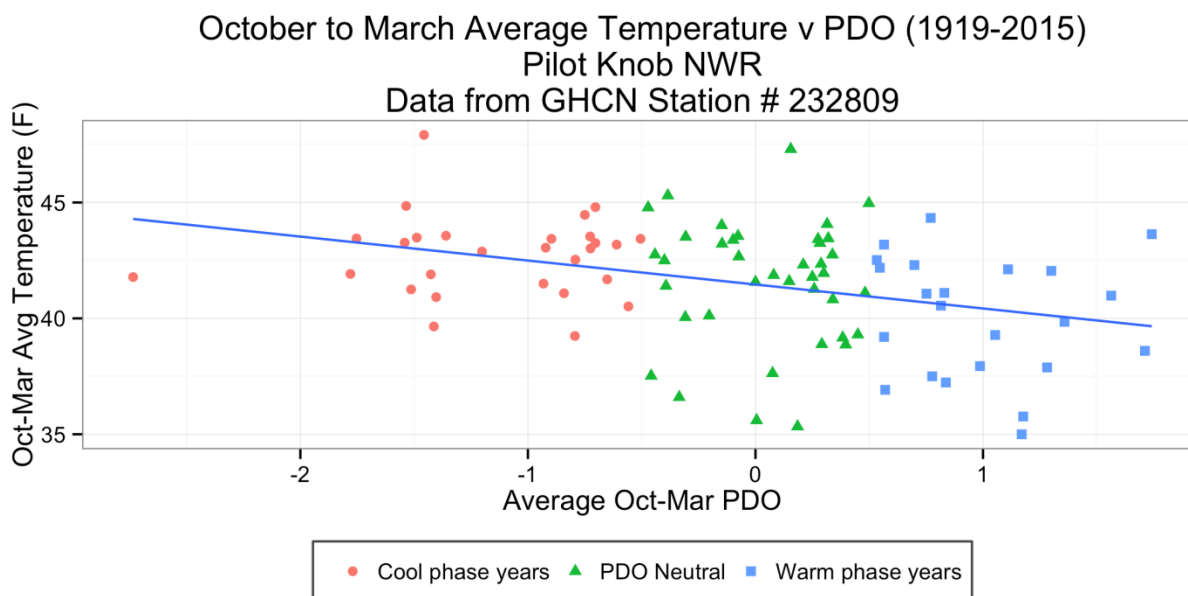


Figure 10.10: Average cool season temperature versus Pacific Decadal Oscillation phase (1919-2015), Station No. 232809, Farmington, MO

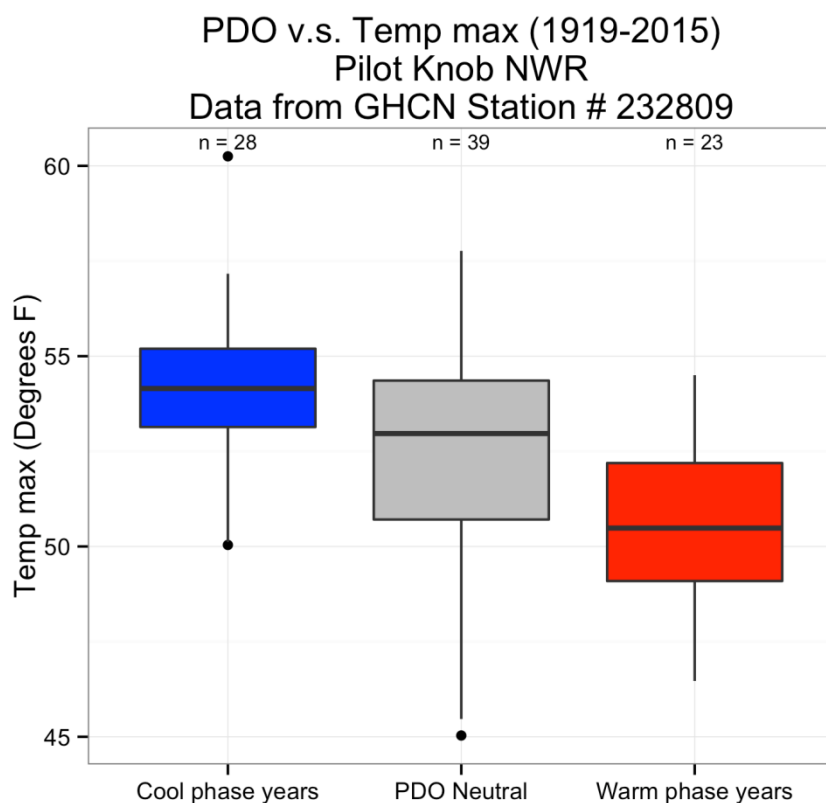


Figure 10.11: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1919-2015), Station No. 232809, Farmington, MO

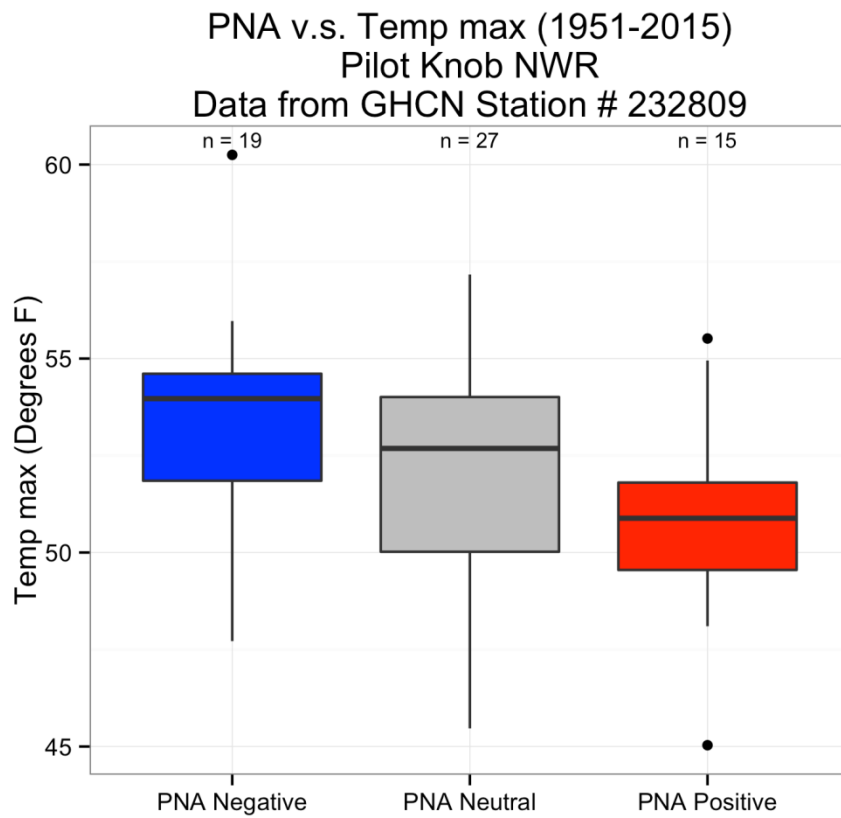


Figure 10.12: Average monthly maximum temperature versus Pacific/North American pattern phase (1919-2015), Station No. 232809, Farmington, MO

Ozark Cavefish National Wildlife Refuge Turnback Cave Unit

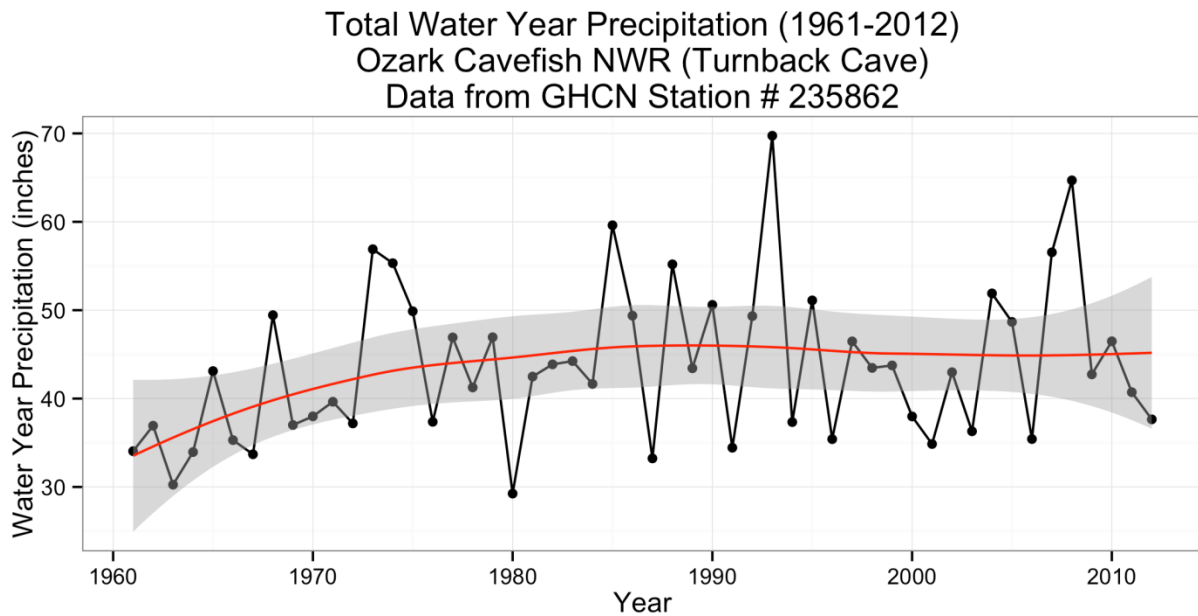


Figure 10.13: Water year total precipitation (1961-2012), Station No. 235862, Mt. Vernon, MO

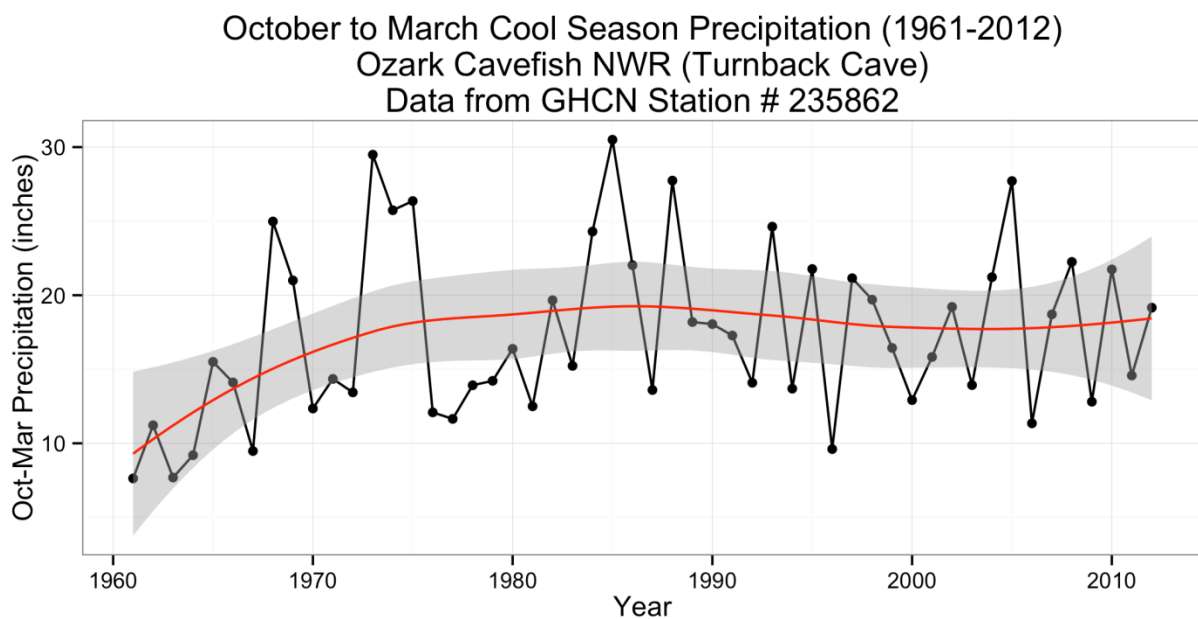


Figure 10.14: Average cool season (Oct-Mar) precipitation (1961-2012), Station No. 235862, Mt. Vernon, MO

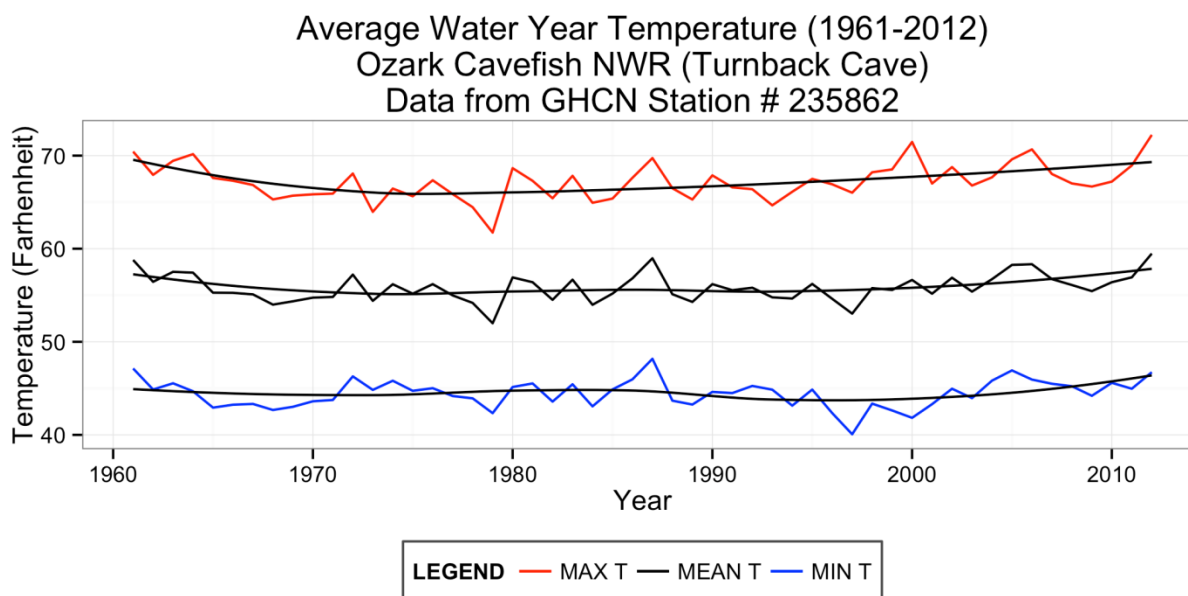


Figure 10.15: Water year average trends in maximum, minimum, and mean temperatures (1961-2012), Station No. 235862, Mt. Vernon, MO

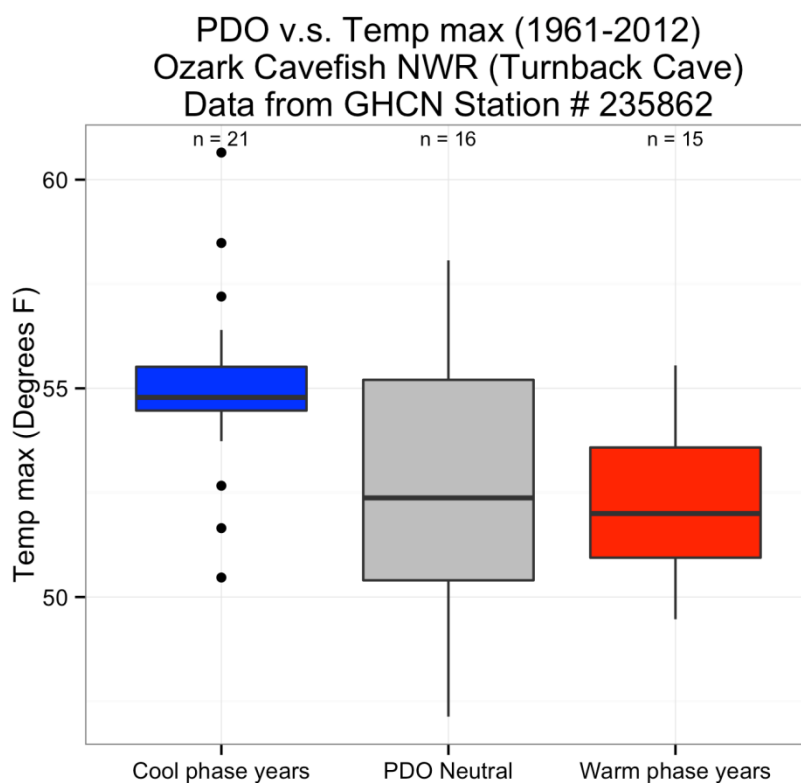


Figure 10.16: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1961-2012), Station No. 235862, Mt. Vernon, MO

Hearrell Spring Unit

Total Water Year Precipitation (1896-2015)
Ozark Cavefish NWR (Hearrell Spring)
Data from GHCN Station # 235976

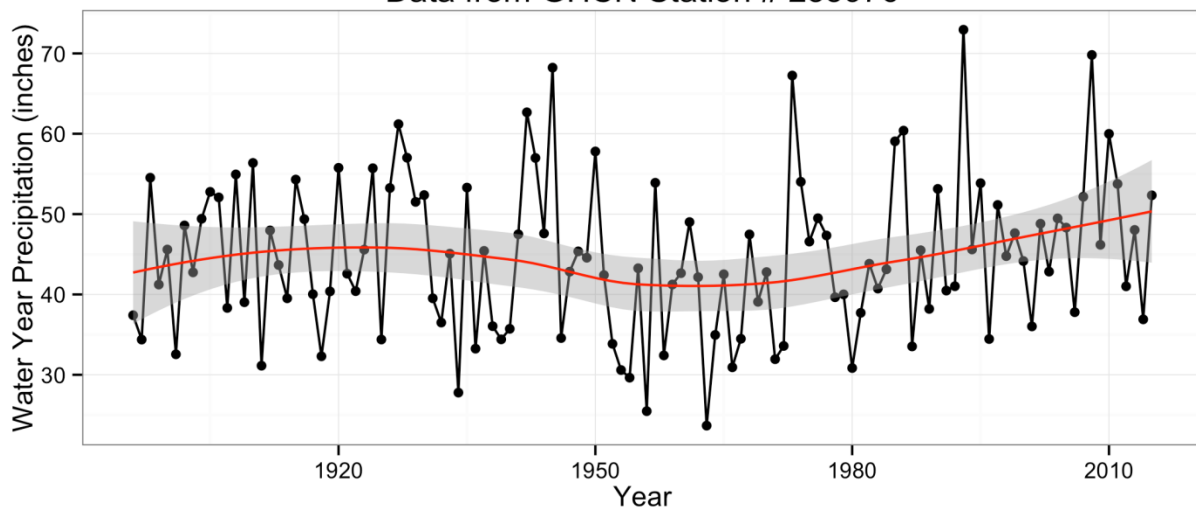


Figure 10.17: Water year total precipitation (1896-2015), Station No. 235976, Neosho, MO

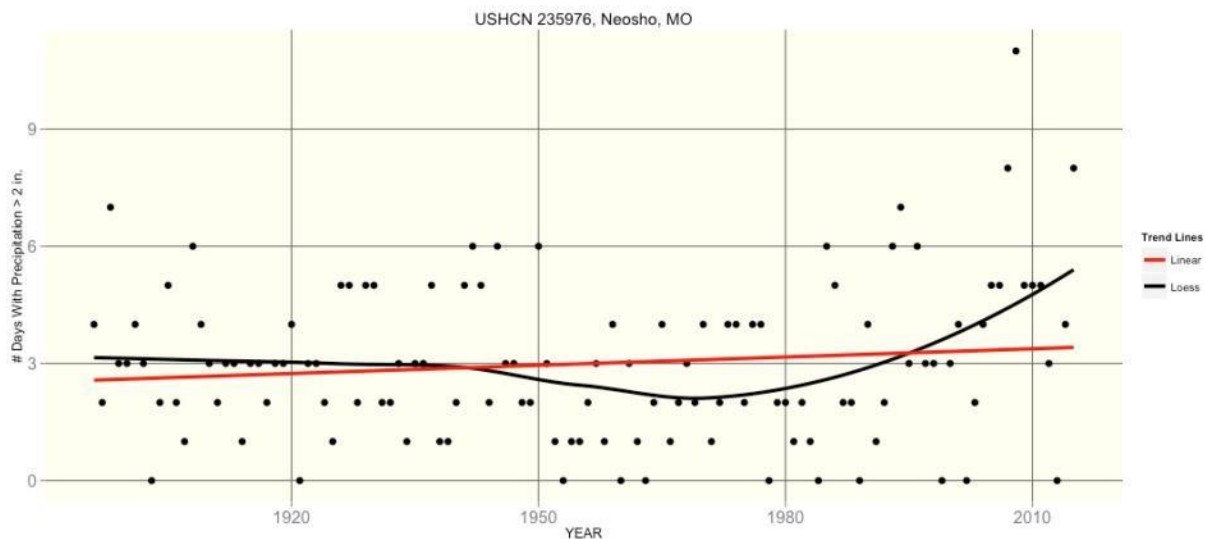


Figure 10.18: Number of days per year with precipitation greater than two inches (1896-2015), Station No. 235976, Neosho, MO

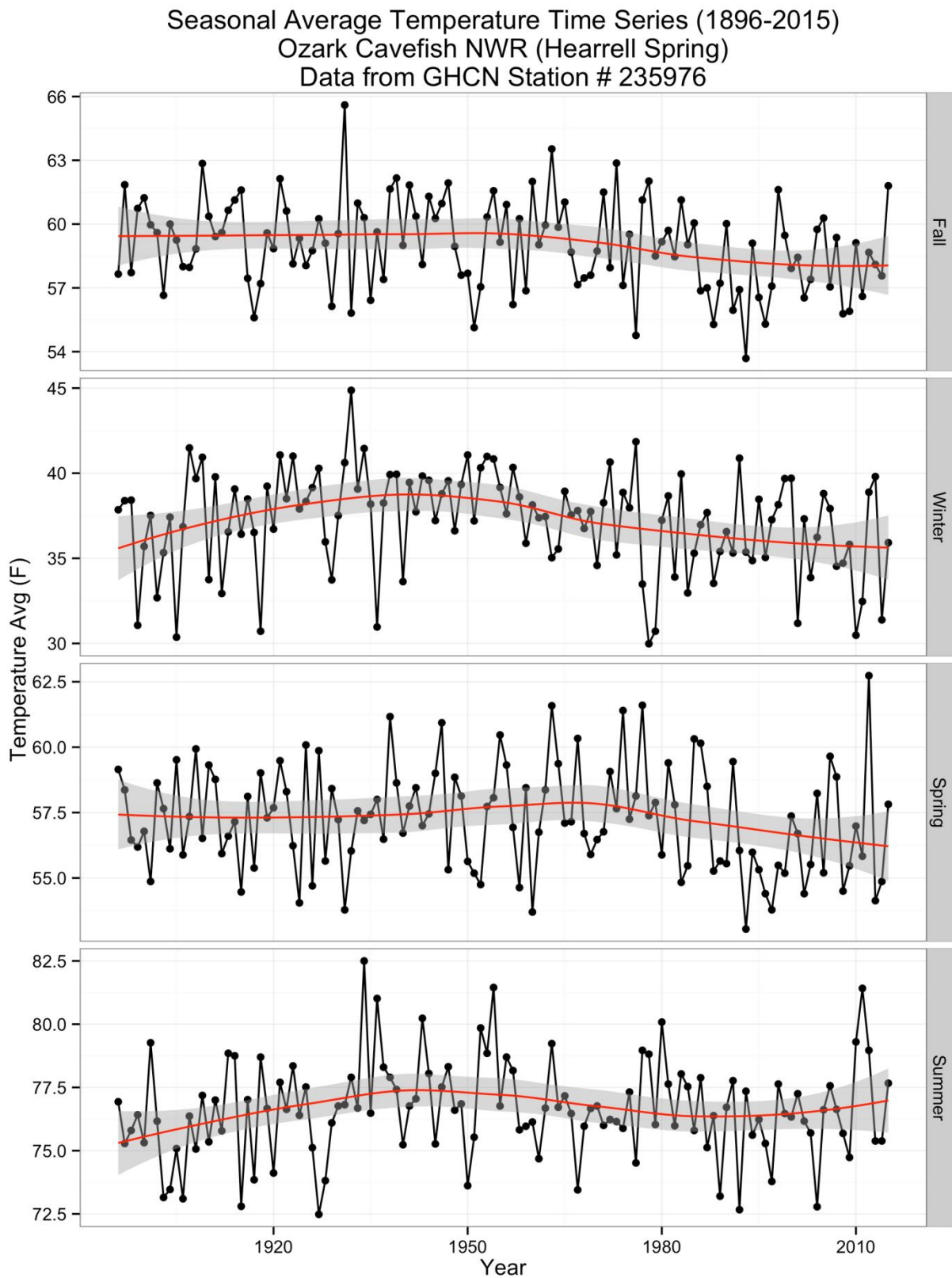


Figure 10.19: Average seasonal temperatures (1896-2015), Station No. 235976, Neosho, MO

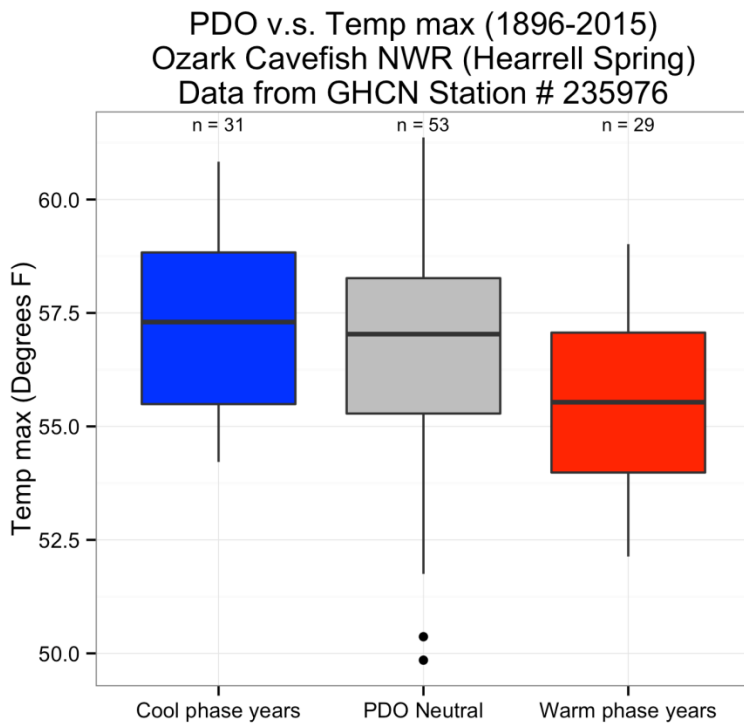


Figure 10.20: Average monthly maximum temperature versus Pacific Decadal Oscillation phase (1896-2015), Station No. 235976, Neosho, MO

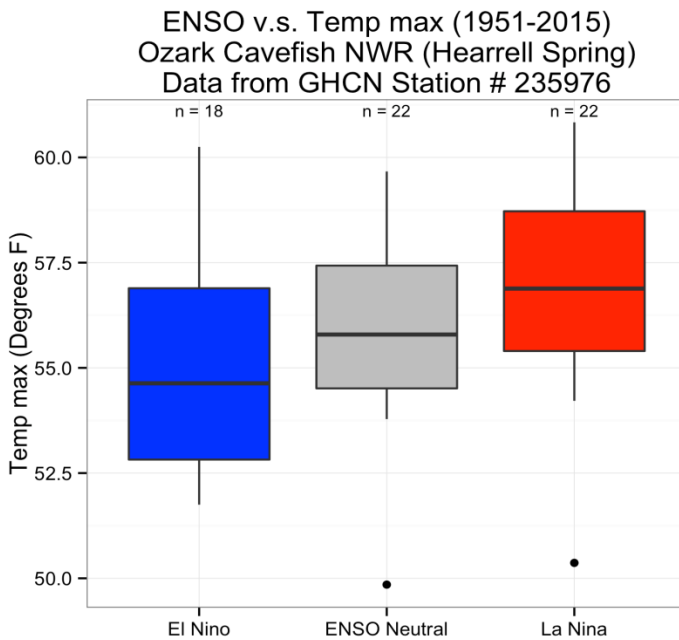


Figure 10.21: Average monthly maximum temperature versus Southern Oscillation Index phase (1896-2015), Station No. 235976, Neosho, MO

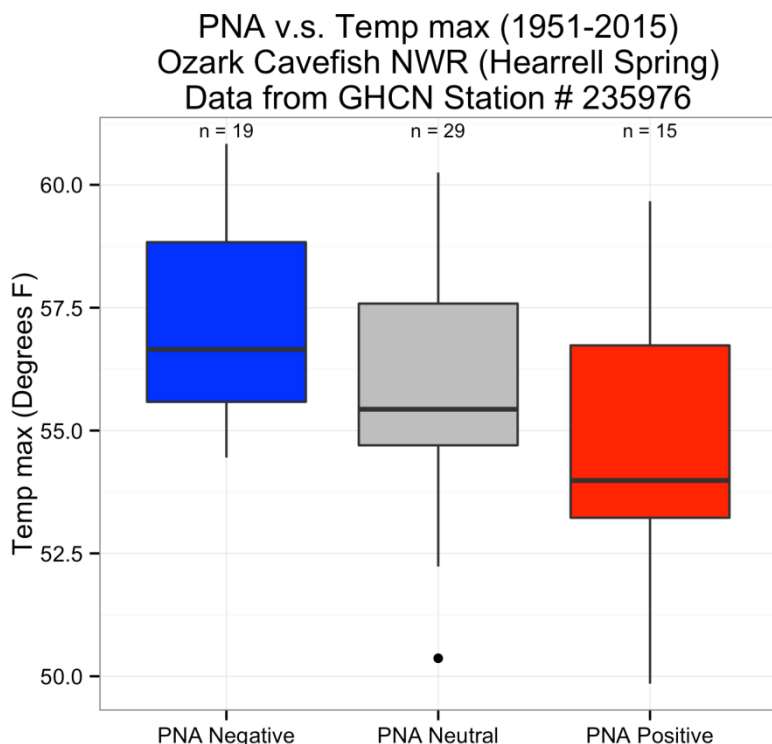


Figure 10.22: Average monthly maximum temperature versus Pacific/North American pattern phase (1896-2015), Station No. 235976, Neosho, MO

11. Appendix C: Refuge Water Management Infrastructure

Unit Name	Acres
Charlie's Thicket	46.5
Fox Pond	11.8
Gum Stump Pool	1363.4
Hartz Pond	0.2
Moist Soil Unit 11 (Luken Farm)	103.1
May Pond	21.9
Monopoly Marsh	2008.7
Moist Soil Unit 1	39.8
Moist Soil Unit 10	46.3
Moist Soil Unit 12	30.2
Moist Soil Unit 2N	43.3
Moist Soil Unit 2S	47.1
Moist Soil Unit 3	43.3
Moist Soil Unit 4N	36.6
Moist Soil Unit 4S	68.5

Moist Soil Unit 4W	13.1
Moist Soil Unit 5	30.2
Moist Soil Unit 6	22.8
Moist Soil Unit 7N	10.9
Moist Soil Unit 7S	10.9
Moist Soil Unit 8E	28.3
Moist Soil Unit 8W	38.2
Moist Soil Unit 9N	29.5
Moist Soil Unit 9S	51.2
MS Pool 6	60.4
MS Pool 8	32.5
Moist Soil Unit Pierman	13.6
Pool 4	1215.5
Pool 5	526.2
Pool 7	1327.0
Pool 8	1876.7
Red Mill Pond	66.6
Rock House Marsh	903.8
Total	10168.1

Table 11.1 Management units and acreage at MNWR

ID	WCS Description	WCS Type
1	N/A	Stoplog
2	N/A	Stoplog
3	N/A	Stoplog
4	N/A	Radial Gate
5	N/A	Stoplog
6	N/A	Stoplog
7	N/A	Stoplog
8	N/A	Stoplog
9	N/A	Stoplog
10	N/A	Stoplog
11	N/A	Stoplog
12	N/A	Stoplog
13	N/A	Spillway
14	N/A	Spillway
15	N/A	Spillway
16	N/A	Earth Plug
17	N/A	Earth Plug
18	N/A	Spillway
19	N/A	Spillway
20	Burris Bridge Staff Gage	Staff

21	Ditch 2 Staff Gage	Staff
22	20' Spillway	Spillway
23	3 42" Pipes	Pipe
24	36" Screwgate	Screwgate
25	42" Screwgate Ditch 6	Screwgate
26	48" Culvert	Box Culvert
27	48" Slide Gate	Slide Gate
28	6" Drain Valve	Valve
29	6" Drain Valve	Valve
30	Company Farms Pump	Pump
31	Cow Creek Box Culvert	Box Culvert
32	Ditch 1 Radial Gate	Radial Gate
33	Ditch 1 Staff Gage	Staff
34	Ditch 10 Screwgate	Screwgate
35	Ditch 10 Staff Gage	Staff
36	Ditch 11 Slide Gate	Slide Gate
37	Ditch 2 Radial Gate	Radial Gate
38	Ditch 2 Red Pump Cage	Pump Cage
39	Ditch 3 Radial Gate	Radial Gate
40	Ditch 3 Slide Gate	Slide Gate
41	Ditch 5' slide gate 6'x10'	Slide Gate
42	Double Screwgates	Screwgate
43	Double Screwgates	Screwgate
44	Double Screwgates	Screwgate
45	Fox Pong Hazard Dam	Dam
46	Gumstump Culvert x2	4' Concrete Pipe
47	May Pond Hazard Dam	Dam
48	Monopoly at Molly's Gage	Staff
49	MS-10 (Binford)	Spillway
50	MS-7N	Stoplog
51	MS-7S	Stoplog
52	MS 1 Stoplog	Stoplog
53	MS 2 N/S Stoplog	Stoplog
54	MS 2 Stoplog	Stoplog
55	MS 2 Stoplog	Stoplog
56	MS 3 Screwgate	Screwgate
57	MS 3 Stoplog	Stoplog
58	MS 4 N/S Stoplog	Stoplog
59	MS 4 Stoplog	Stoplog
60	MS 4W	Stoplog
61	MS 5 Stoplog	Stoplog
62	MS 6 Stoplog	Stoplog
63	MS 8 Screwgate	Screwgate

64	MS 9 South Stoplog	Stoplog
65	Overflow	Spillway
66	Pool 8 Stoplog 4x 48"	Stoplog
67	Red Mill Pond Stoplog	Stoplog
68	Rockhouse Marsh Radial Gate D11	Radial Gate
69	South Radial Gate	Radial Gate
70	Stanley at Molly's Gage	Staff
71	Stanley Creek Structure Flat Banks	Stoplog
72	Well Pump	Pump

Table 11.2. Water Control Structures found at MNWR

Structure	Elevation (ft)	Optimal elevation (ft, 2016)	Measurement to optimal (ft)
MS1	339.852	337.75	2.1
MS2 S south SL	340.022		
MS 2 S Agridrain no lid (SE corner box)	340.846	339	1.846
MS2N	339.163	338.35	0.813
MS3 Screw	339.727		
MS3 SL	340.058	338.8	1.206
MS3 Slide Gate	340.915		
MS4 N agridrain no lid (NW corner of box)	340.633	338.75	1.883
MS4 N to 4S west SL	340.209		
MS4 N to 4S east SL	340.662		
MS4 S	341.141	338	2.141
MS4 W	340.183	338.85	1.333
MS5	339.094		
MS6	338.726	338.1	0.626
MS7 S	342.995	340	2.995
MS 7 N	342.152	339.75	2.402
MS8E- 9N	342.522	340	2.522
MS8E- 9S	342.299		
MS8E - 8W	342.578		
MS 8W- 9S	341.134		
MS 9S - D10	340.239		
MS 9N - D10	340.423		
MS 12	340.823		
Charlie's	343.513		
Redmill SL	341.912		
Peirman	338.477		

D1 RG (east)	343.221
D2 RG	342.486
D3 SG	341.394
D3 RD	340.865
The horn Gum Stump south	337.473
The horn Gum Stump north	337.384
D 5 Slide	342.51
D11 Slide	344.97
D10 Screw Gate	337.119
Spillway	343.48
D2 Pump (se corner)	342.657
Pool 8 SG	339.615
Pool 8 SL	340.724
D11 RG concrete	344.97

Table 11.3: Water Control Structure elevations at MNWR



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